Olivier from cosmic dawn to cosmic noon

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A tribute to Olivier Le Fèvre. 4-8 July 2022

Timeline

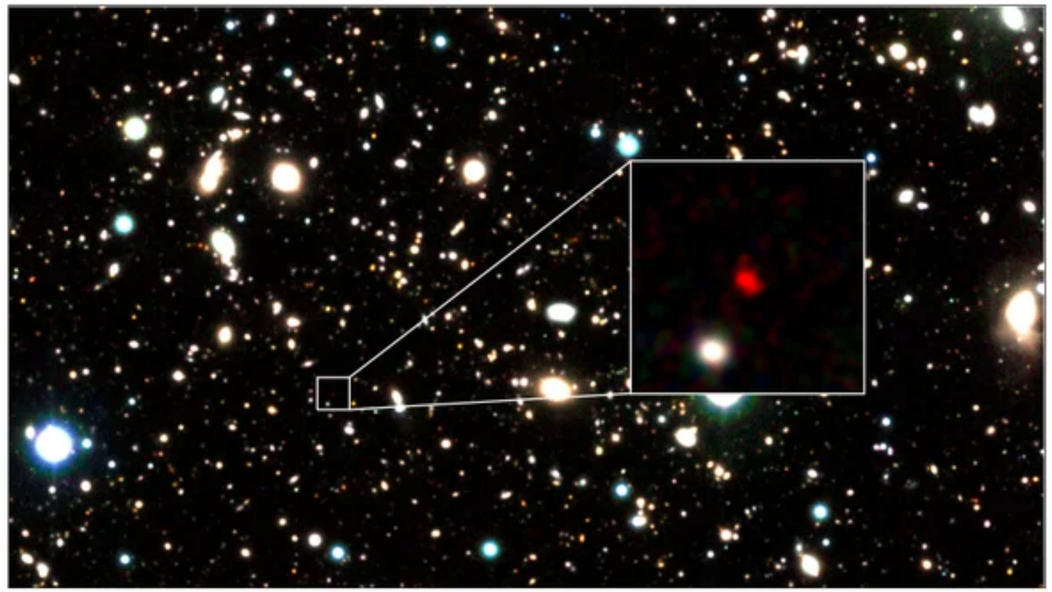
- June 2003: first glimpse of Olivier at a Mykonos conference
- December 2006-June 2008: first stay in Marseille
- July 2011-June 2014: second stay in Marseille…
- July 2014: I move to Chile
- January 2018: back to Padova

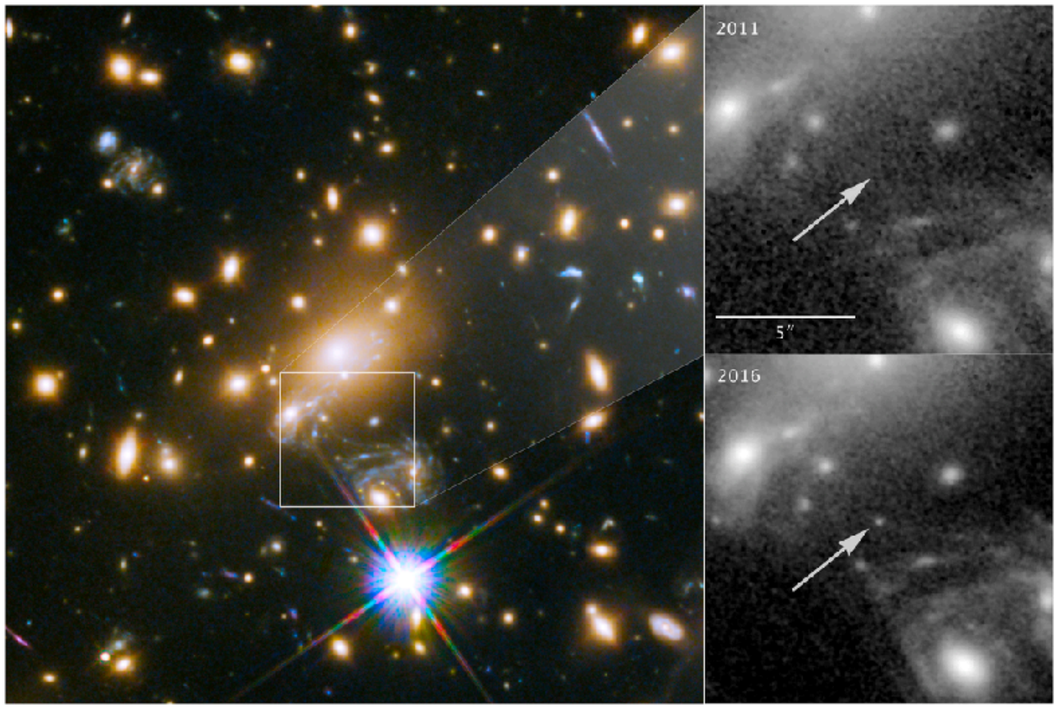
The only photo of me and Olivier

Something not particularly stimulating for Olivier

COSMOLOGY

Astronomers Spot Most Distant Galaxy Yet, 13.5 Billion Light-Years from Earth



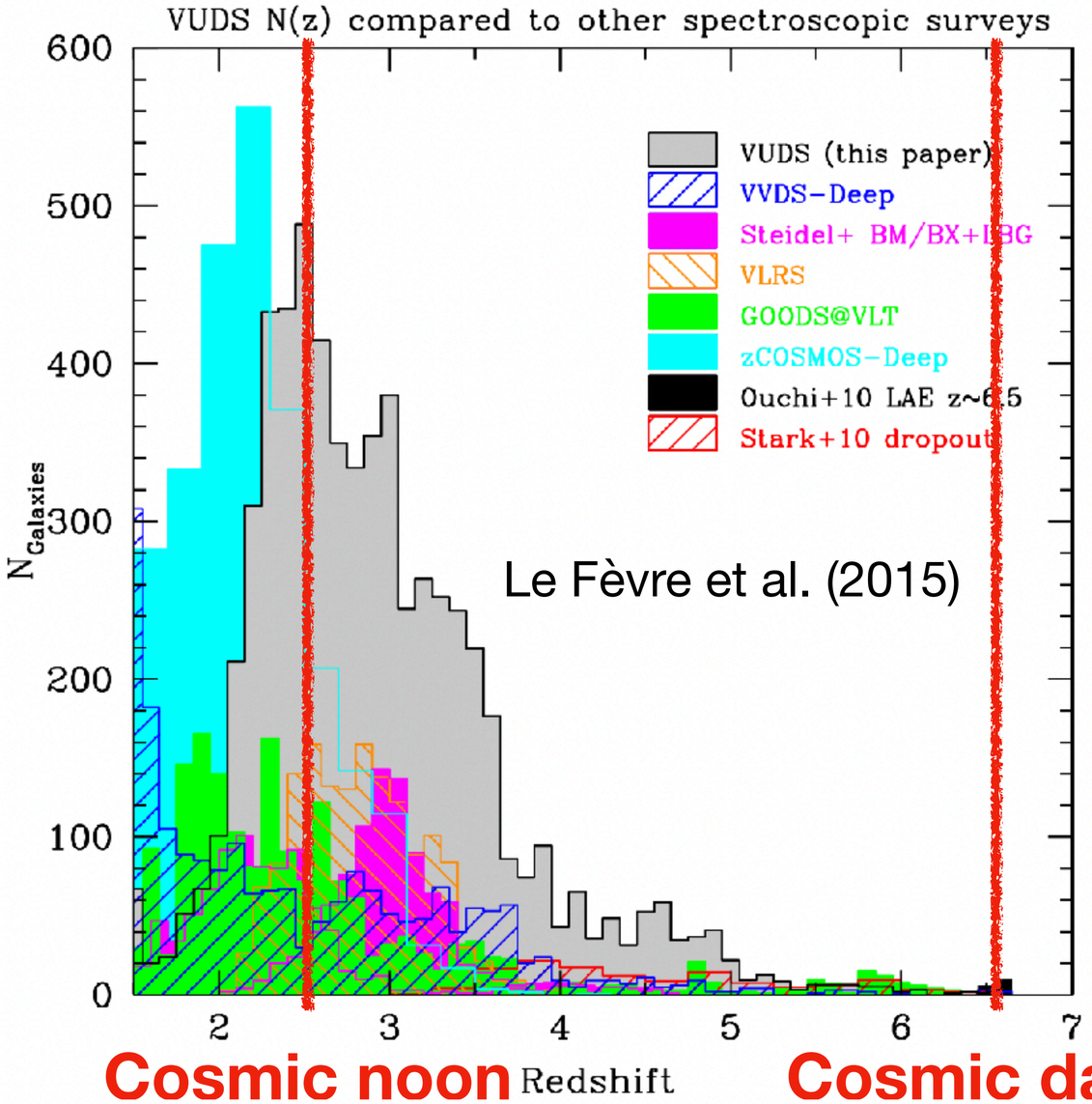


Apr 2, 2018

Hubble Uncovers the Farthest Star Ever Seen

The farthest ***put your favorite object here* ever found!!!**

..you need samples to learn something

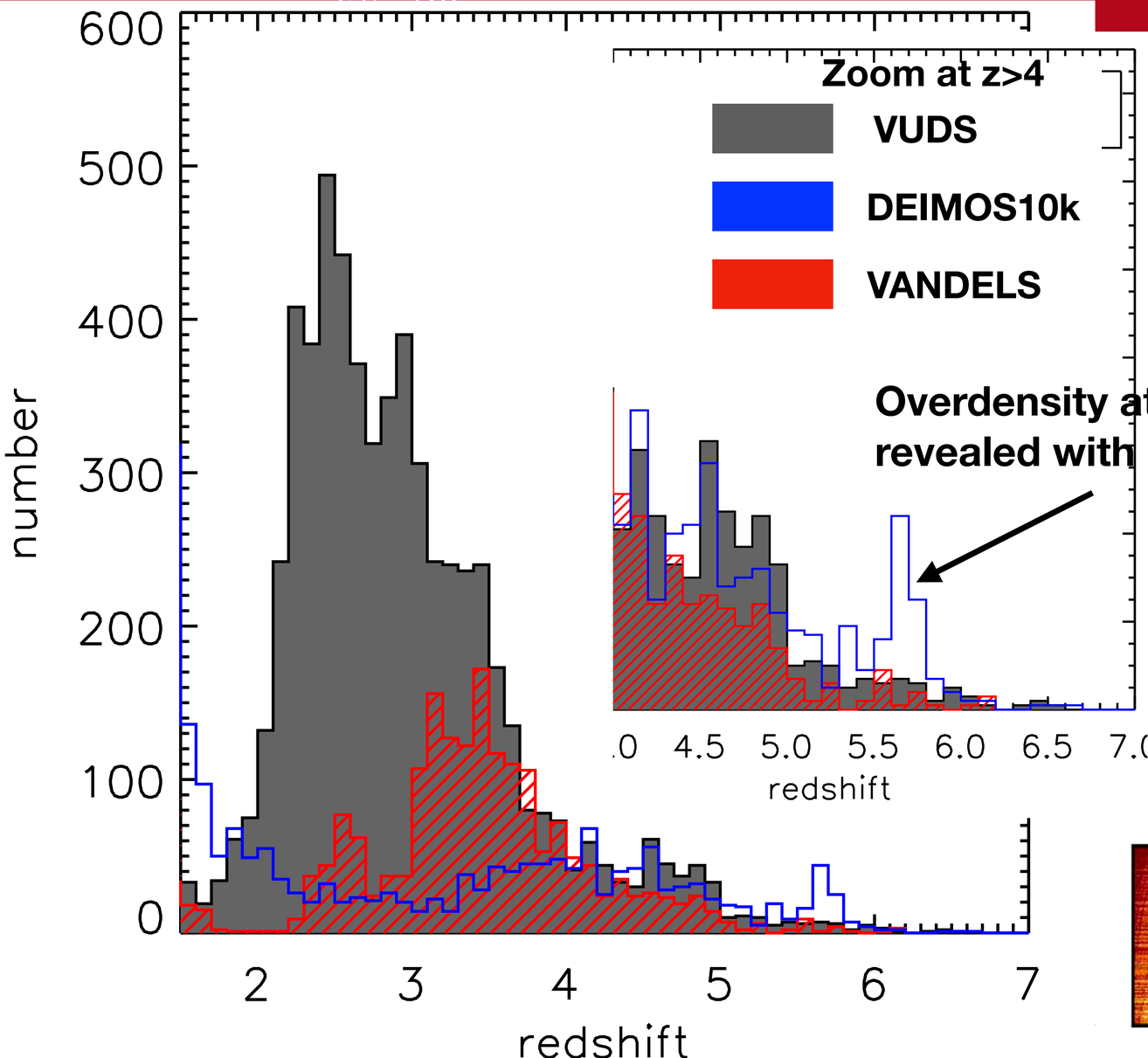


Cosmic noon **Cosmic dawn**

- ~**4000** galaxies with **z>2**, good flag
- ~**350** galaxies with **z>4**, good flag
- m_i<25 (main-sequence up to z~6)

This is something to be proud of!

Comparison with DEIMOS10k and VANDELS



ll the highest numbers at z~2.5

…and also at z=4-6

Outline of the talk

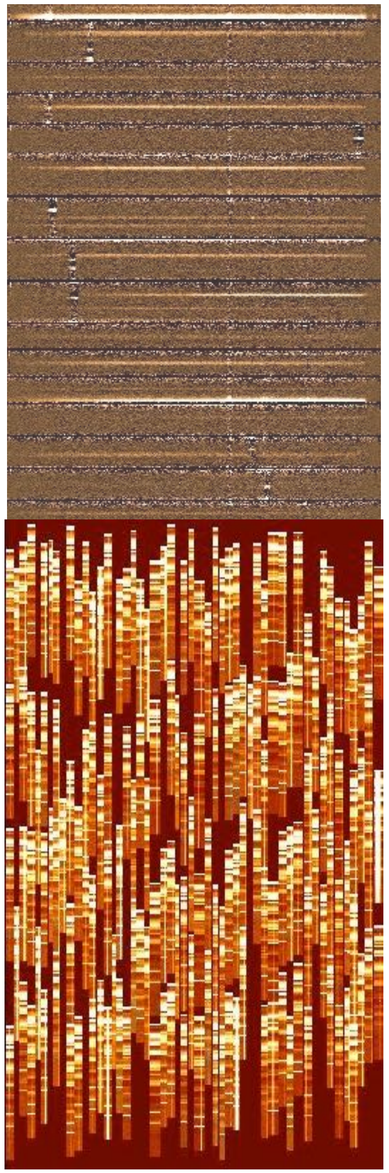
A very biased, not very coherent, selection of:

1. Science enabled by large VIMOS spectroscopic samples at z > 2

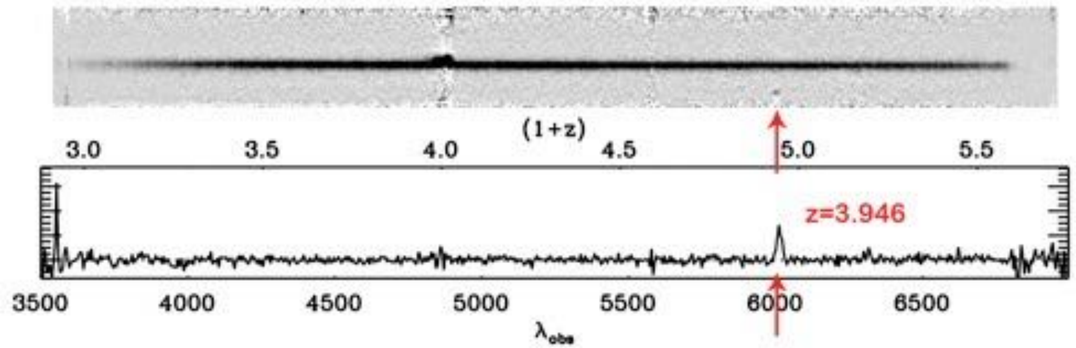
2. Projects not planned in the proposals

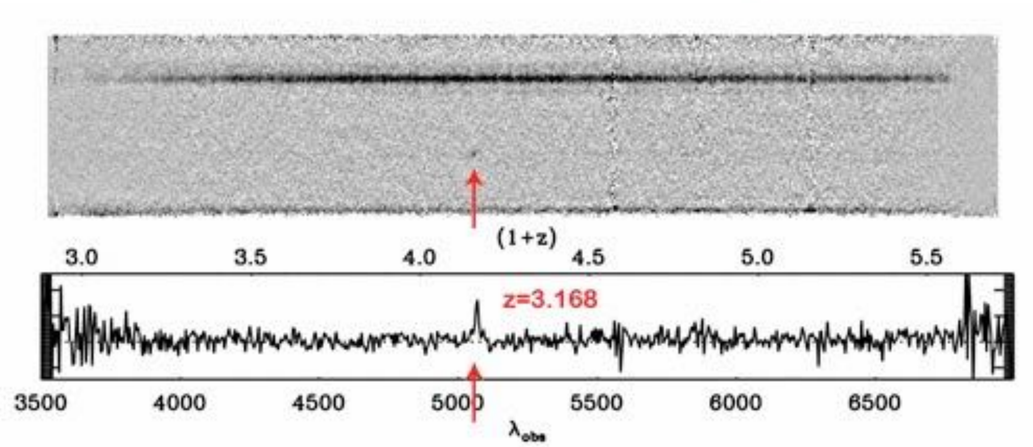
this is really something Olivier always pushed us to do…

Unplanned project 1



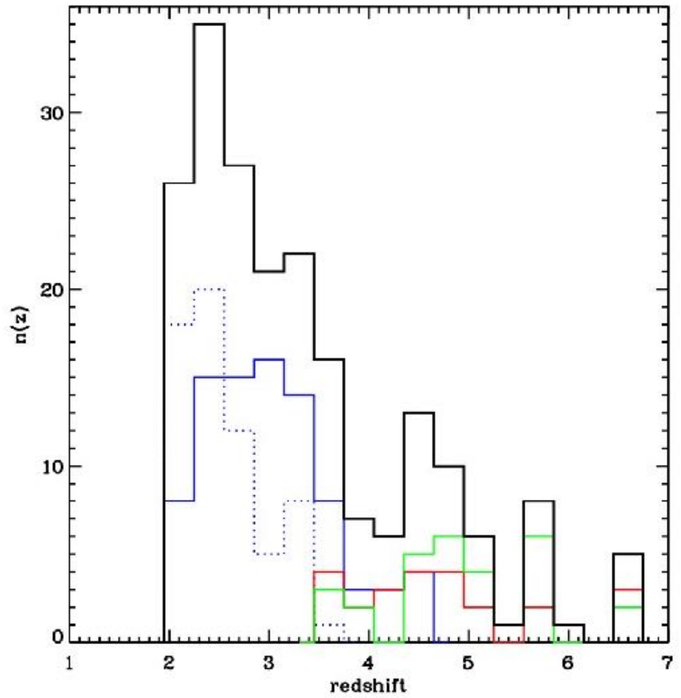
Look for serendipitous LAE!!



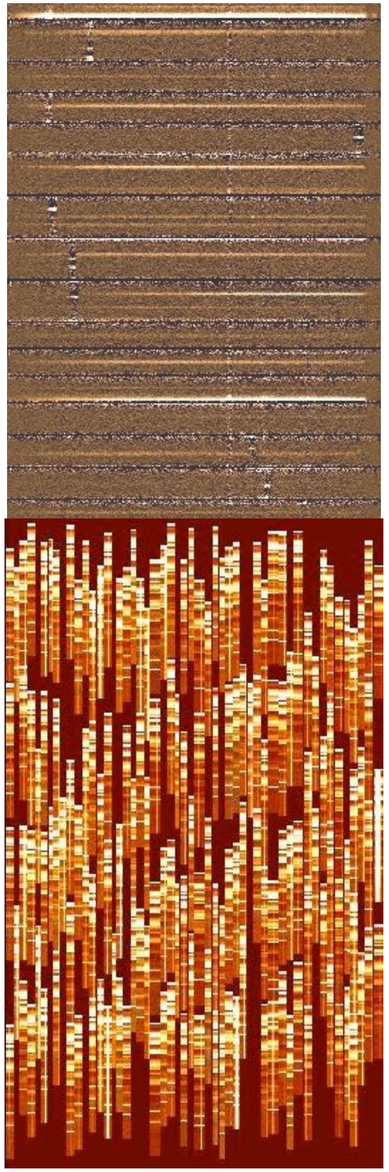


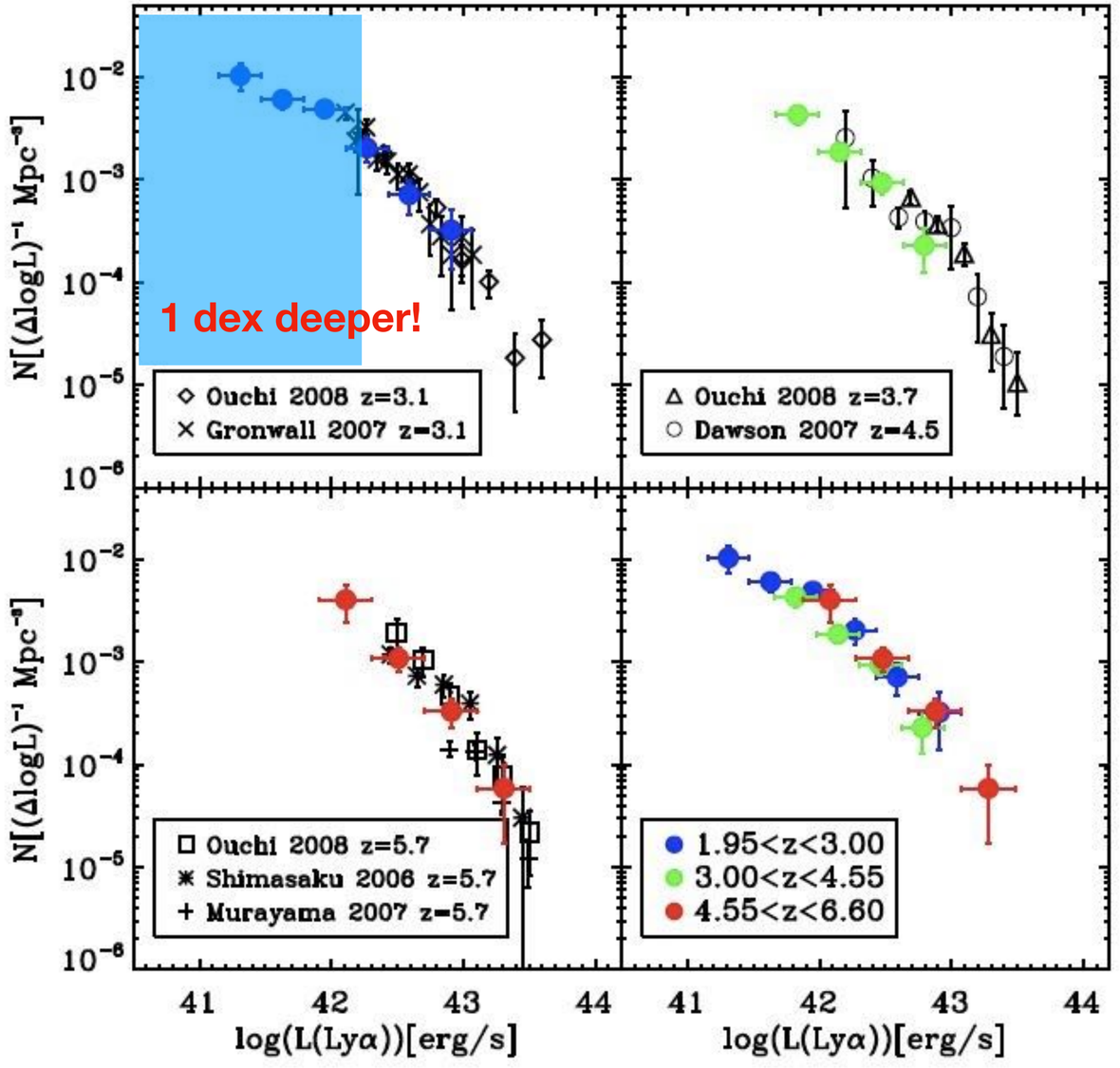
PC, Le Fèvre et al. (2011)

- **Flux limited** more than EW limited
- 3.3 arcmin^2 down to F > 1.5x10^{18}
- 22.2 arcmin^2 down to F > 5x10^{18}
- **217 serendipitous Lyα emitters**
- **Deeper than literature: LF slope**
- Long spectral baseline: check for other lines and exclude contaminants



Evolution of the Lya LF

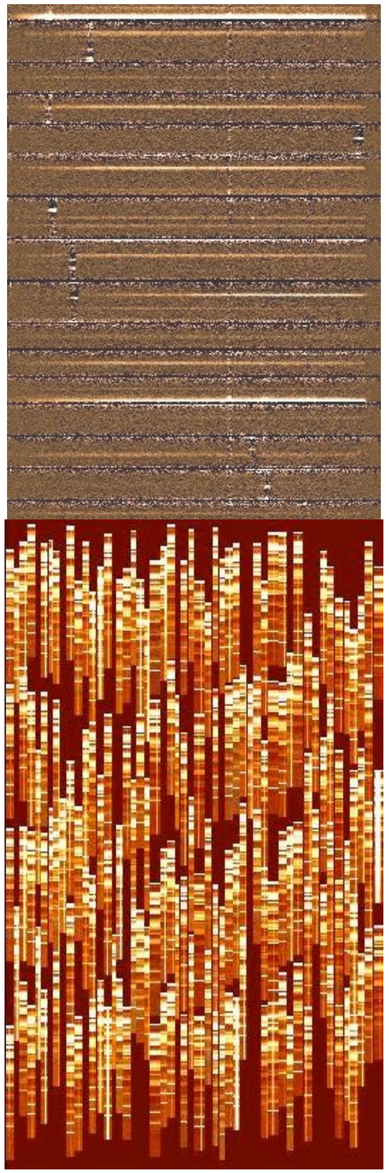




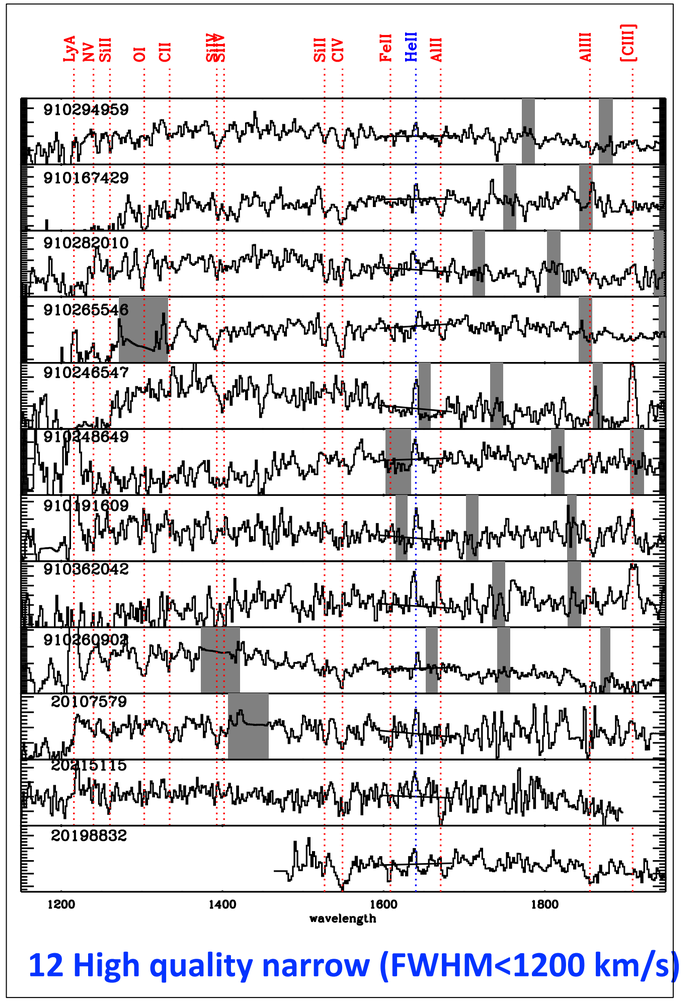
- Mild evolution, or consistent with no evolution from z=2 to z=6
- we reach L=2x10^{41}erg/s (1/10 L*): we can constrain the slope up to z~4!!!
- Very steep faint end: α=-1.6 -1.8

PC, Le Fèvre et al. (2011)

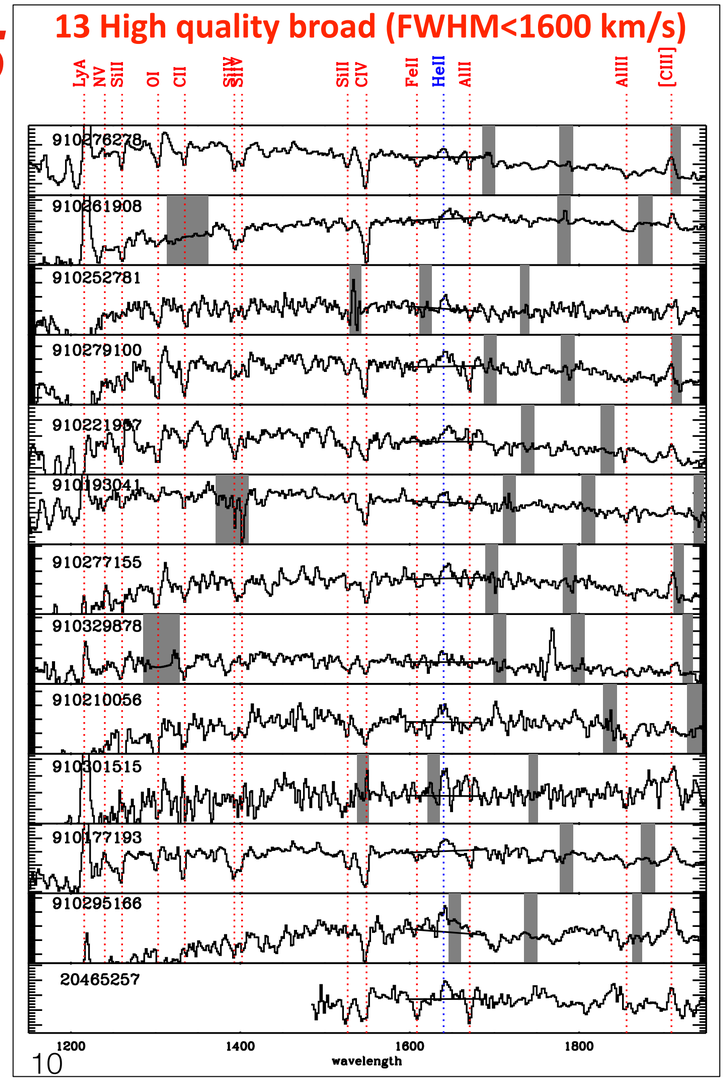
Unplanned project 2



Look for peculiar populations: HeII emitters at 2<z<4.5



12 High quality narrow (FWHM<1200 km/s)

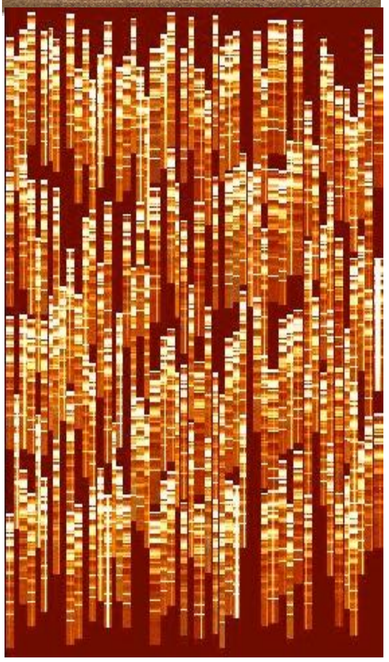


352 galaxies 2<z<4.5

- 12 narrow HeII
- 13 broad HeII
- 12 low quality HeII
- 3 AGN

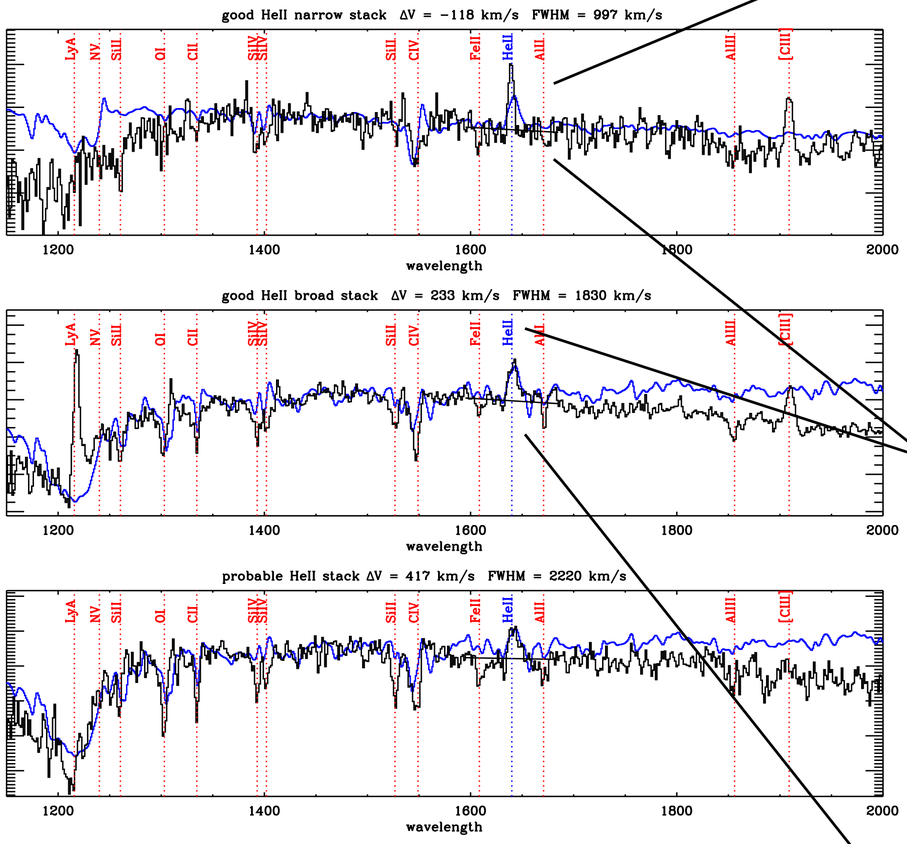
PC, Le Fèvre et al. (2013)

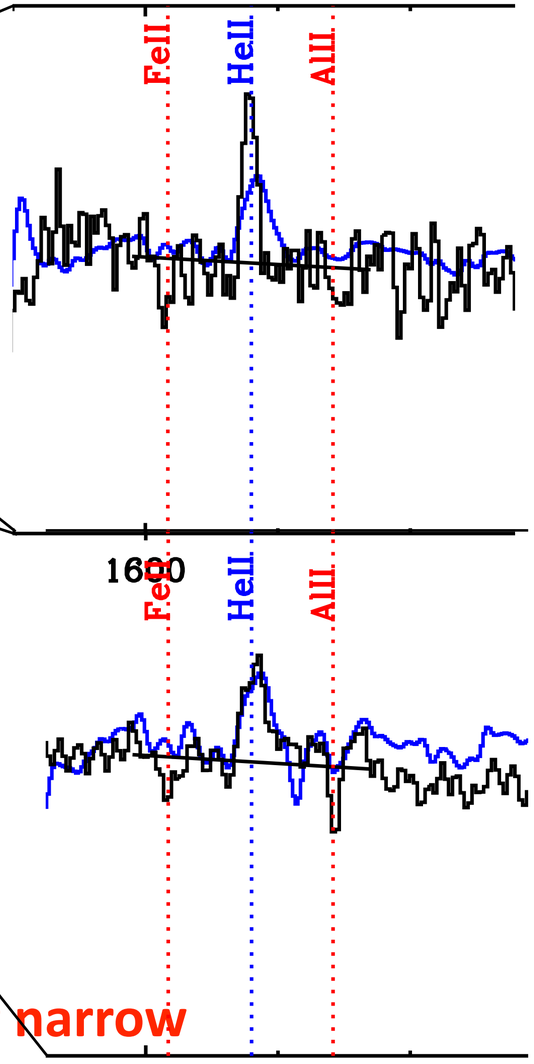
HeII emitters at 2<z<4.5



What powers the HeII emission?

Stacks of the HeII emitters





- Cooling radiation unlikely
- WR stars: only for broad
- AGN unlikely: no other emission lines, narrow emission
- ***Pockets of PopIII?***

PC, Le Fèvre et al. (2013)

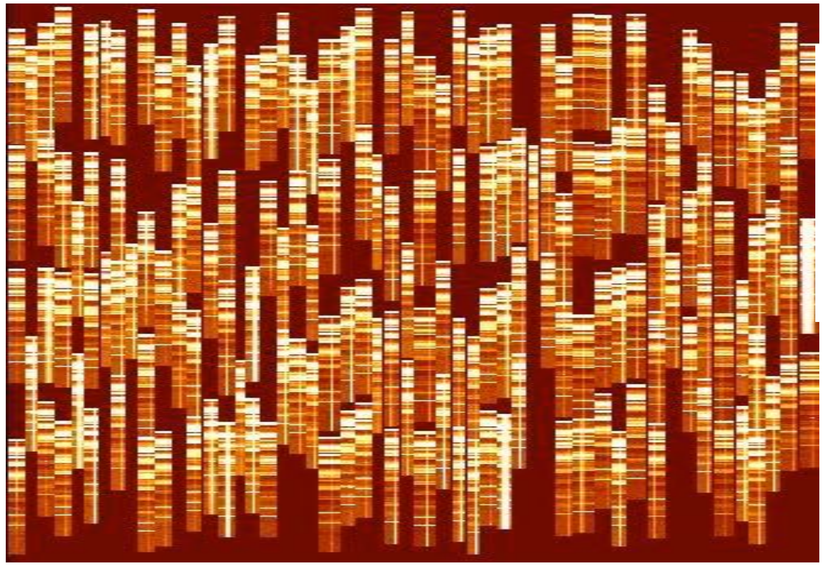
See also Nanayakkara+19 including VUDS data

model: SSP + Wolf Rayet phase:

good for Broad emitters, not for narrow

> 2011

X 10 =

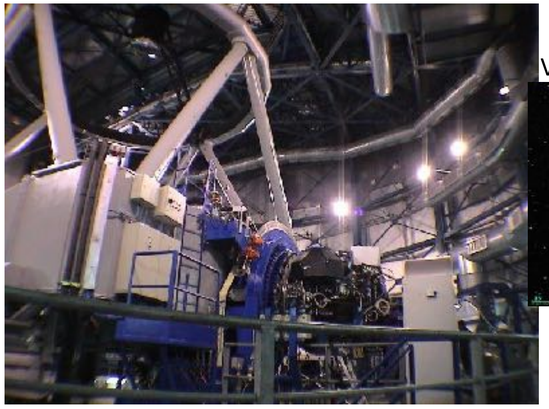


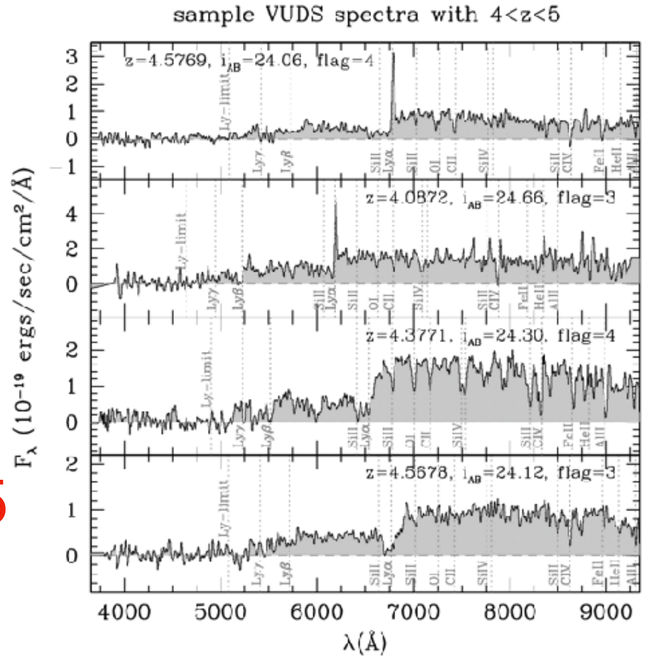
O. Le Fèvre[1], L.A.M. Tasca[1], P. Cassata[1], B. Garilli[3], V. Le Brun[1], D. Maccagni[3], L. Pentericci[4], R. Thomas[1], E. Vanzella[2], G. Zamorani[2], E. Zucca[2], R. Amorin[4], S. Bardelli[2], P. Capak[12], L. Cassarà[3], M. Castellano[4], A. Cimatti[5], J.G. Cuby[1], O. Cucciati[5,2], S. de la Torre[1], A. Durkalec[1], A. Fontana[4], M. Giavalisco[13], A. Grazian[4], N. P. Hathi[1], O. Ilbert[1], B. C. Lemaux[1], C. Moreau[1], S. Paltani[9], J. Pforr[1], B. Ribeiro[1], M. Salvato[14], D. Schaerer[10,8], M. Scodeggio[3], V. Sommariva[5,4], M. Talia[5], Y. Taniguchi[15], L. Tresse[1], D. Vergani[6,2], P.W. Wang[1], S. Charlot[7], T. Contini[8], S. Fotopoulou[9], C. López-Sanjuan[11], Y. Mellier[7], and N. Scoville[12]

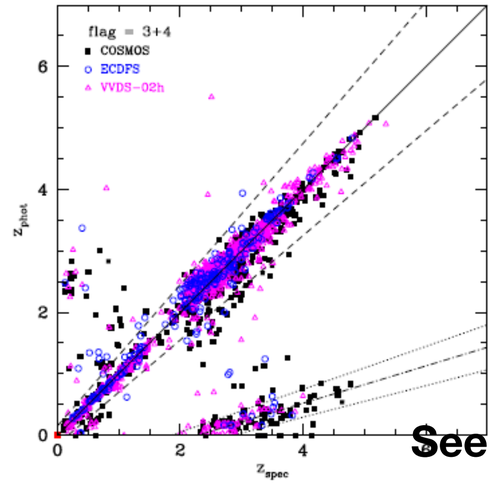
VUDS | VIMOS Ultra Deep Survey

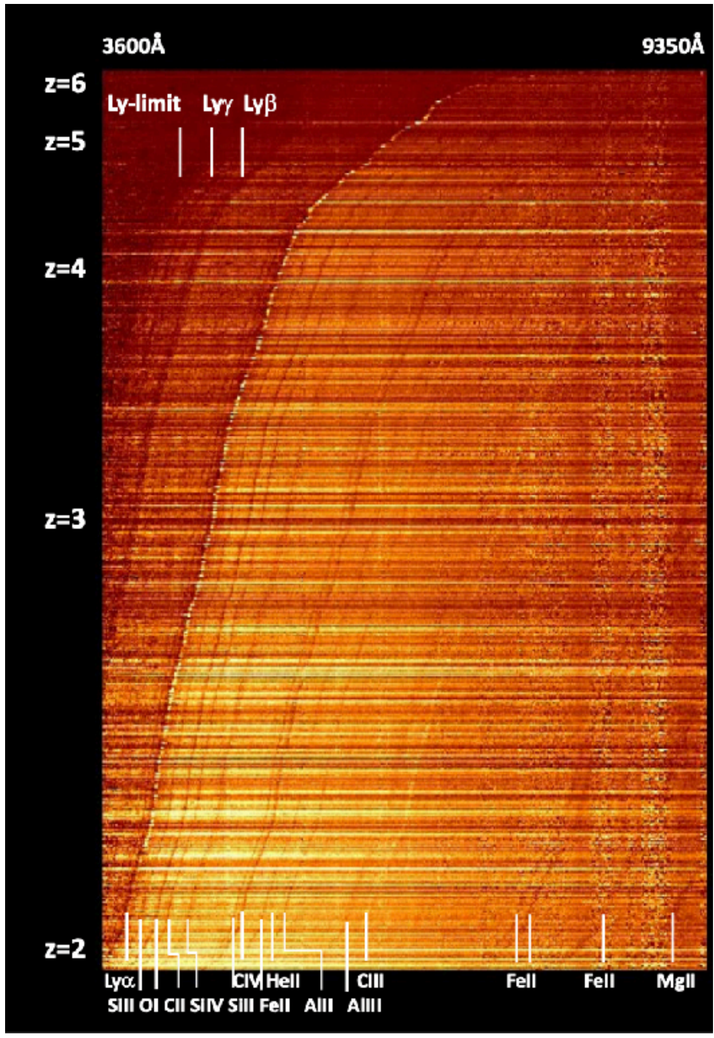
VUDS in a nutshell

- ESO large program
- Focused on 2<z<6
- 1 deg²
- 10,000 targets
- 3 fields: mitigate cosmic variance
- Selection: photo-z + SED + color, $i_{AB} \leq 25$
- 14hr integration over 3600-9300Å
- 8000 galaxies with $0 < z_{spec} < 6.5$





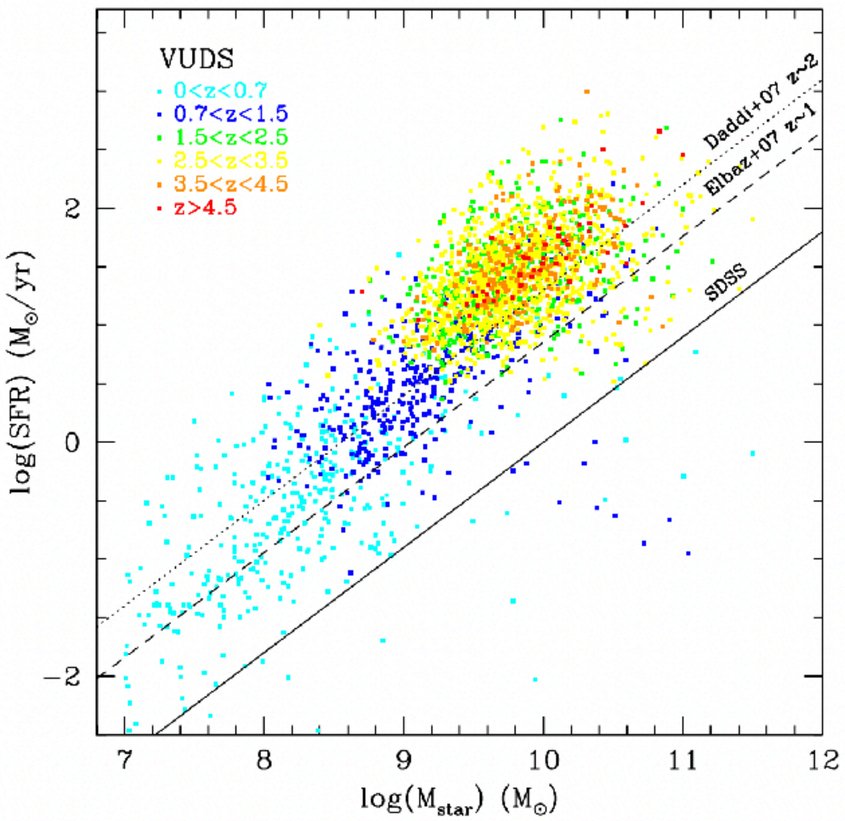




See also Lidia's talk and Romain's poster!!!

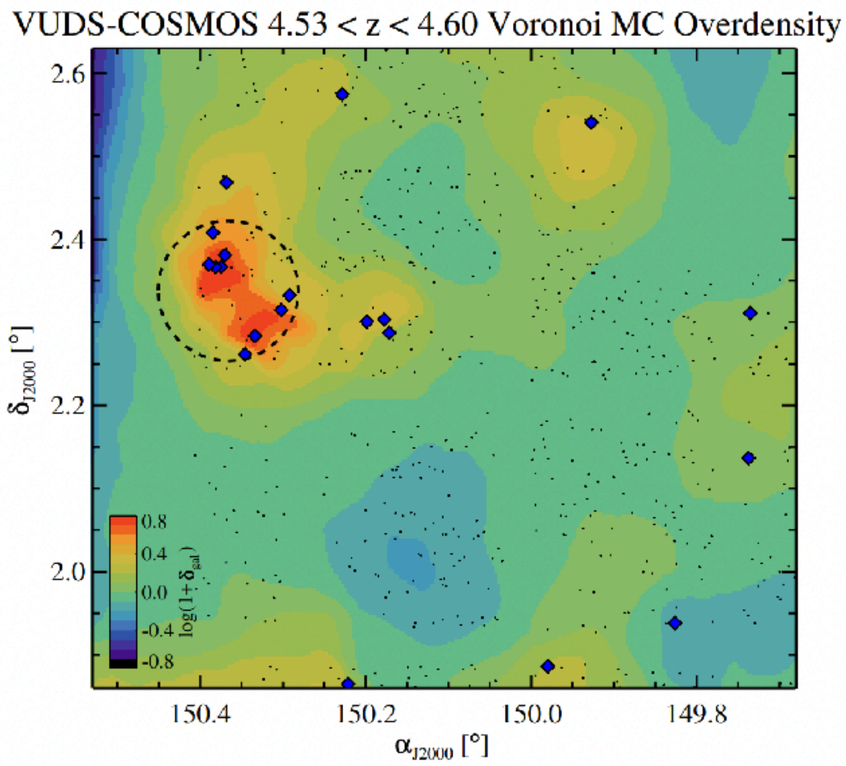
VUDS: what kind of galaxies?

All main-sequence



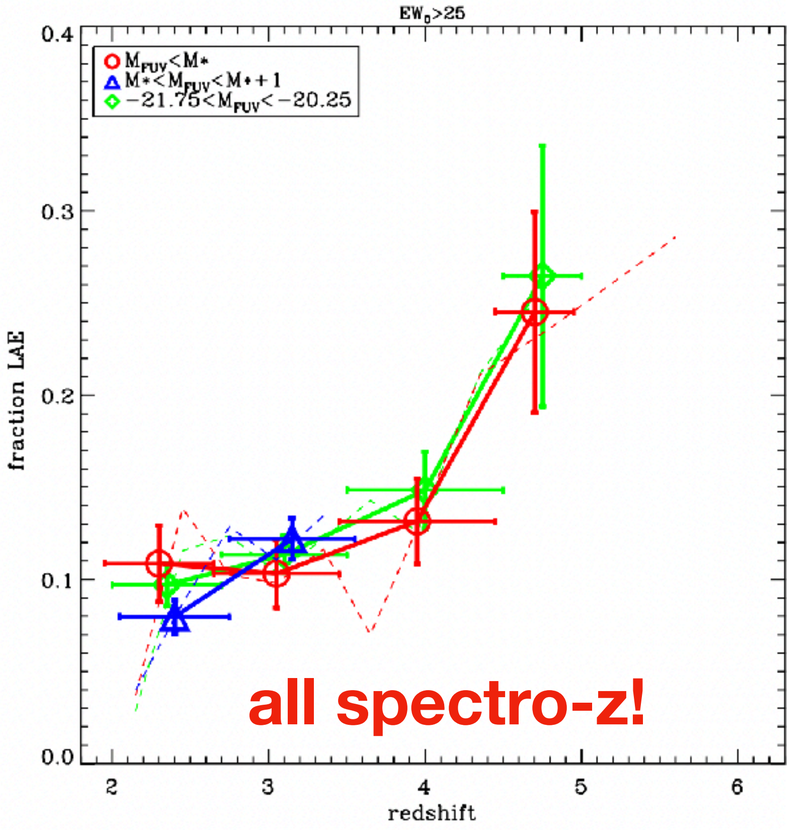
Tasca, Le Fèvre+15

Across different environments



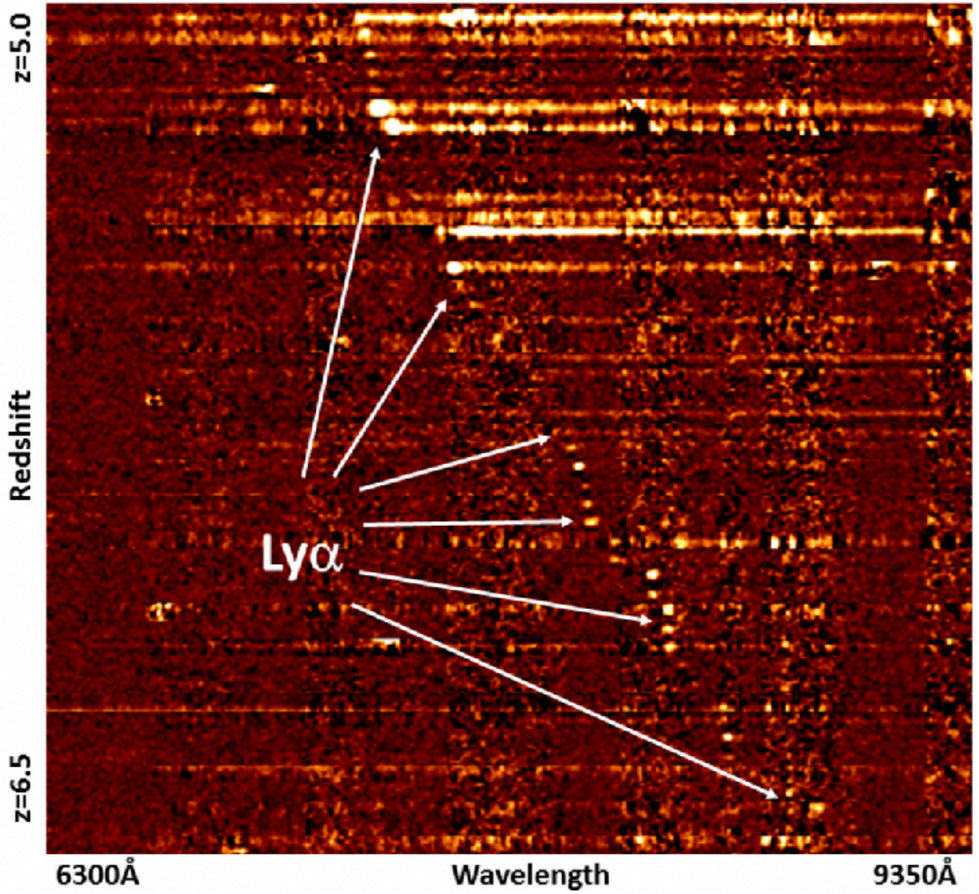
Lemaux+14, Cucciati+14,
Lemaux+18, Cucciati+18

Evolving ISM: Lya fraction increases with z



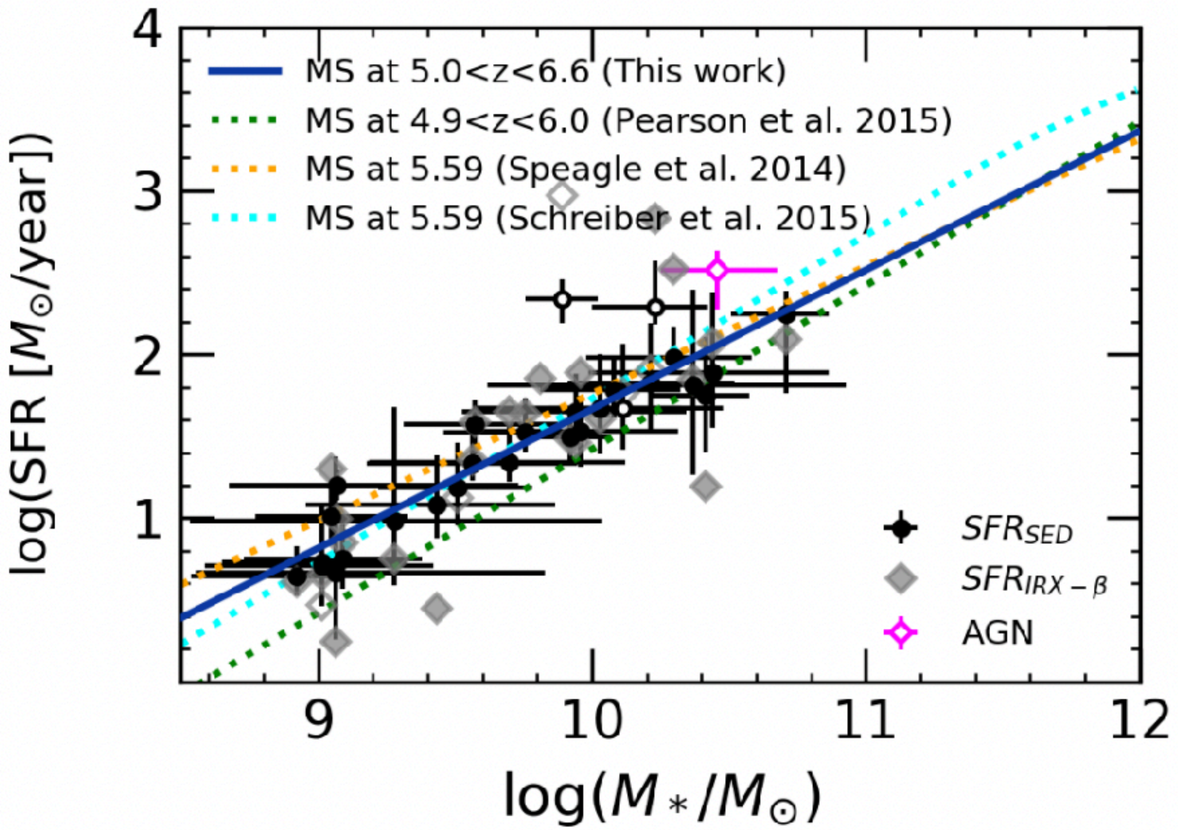
Cassata, Le Fèvre+15

VUDS probes the cosmic dawn



48 galaxies with spectro-z at 5<z<6.5

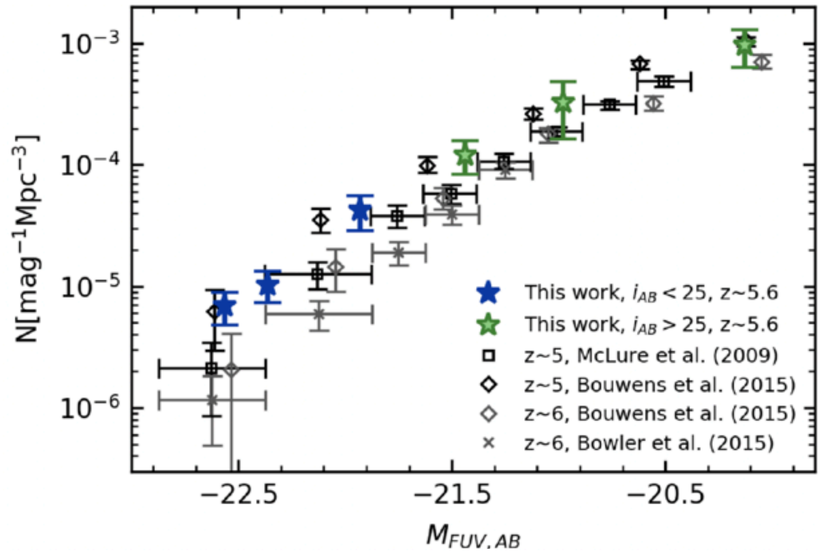
Main-sequence at 5<z<6.5

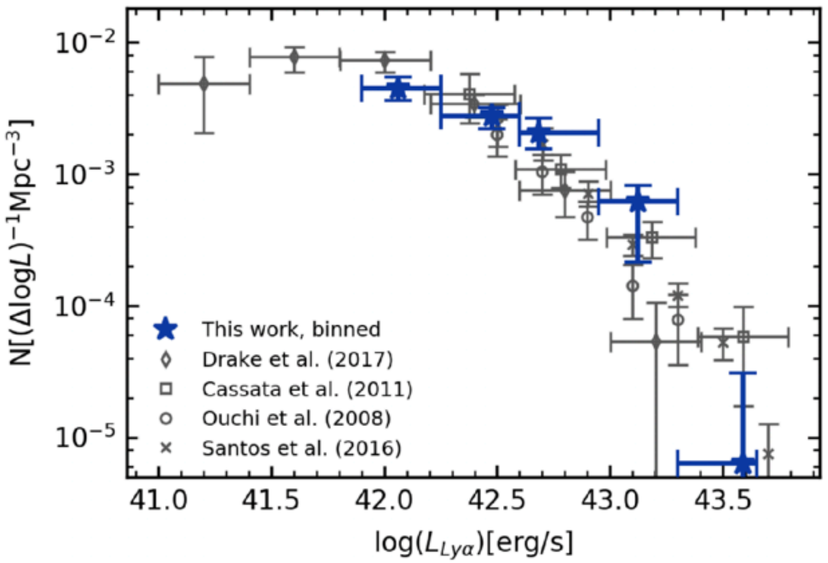


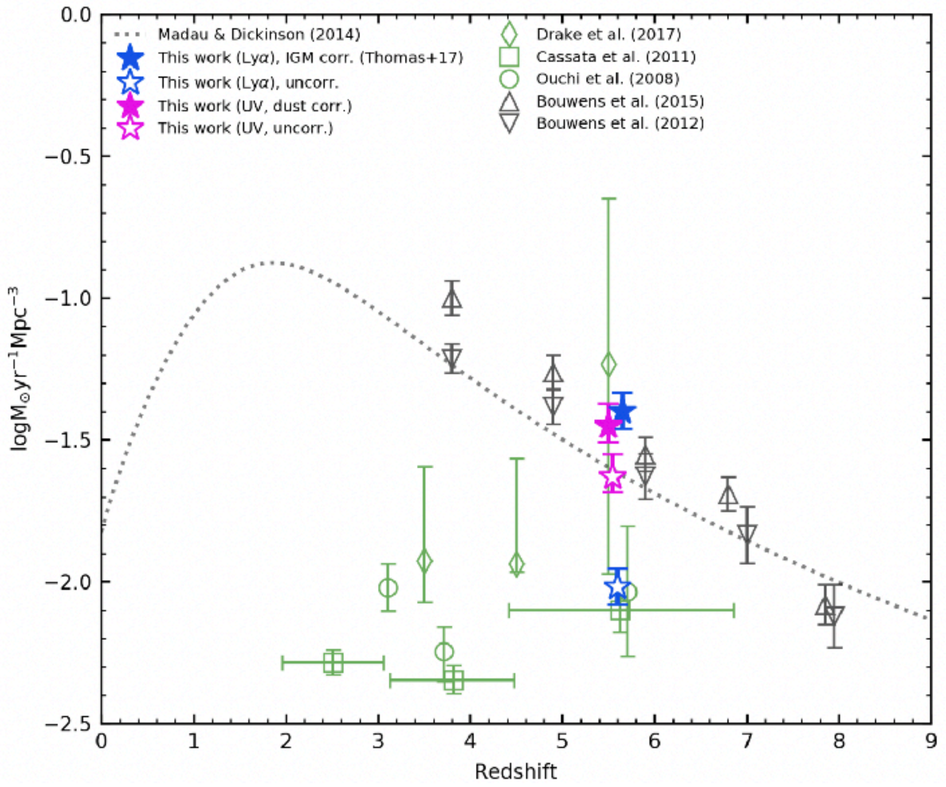
Khusanova, Le Fèvre, PC et al. (2020)

VUDS | VIMOS Ultra Deep Survey

VUDS probes the cosmic dawn







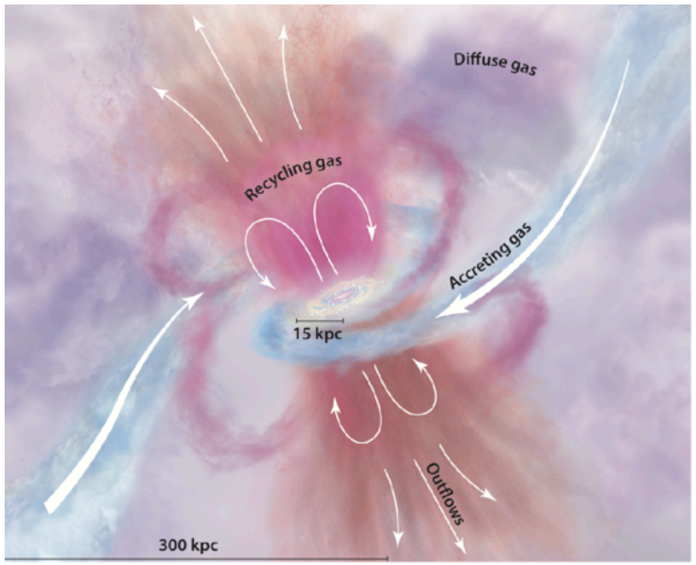
- MS extends beyond z=5
- Probed the bright end of the Lya LF
- SFRD(Lyα)/SFRD(UV)~1
- A lot of SFR could be hidden by dust

Khusanova, Le Fèvre, PC et al. (2020)

Unplanned 3: CGM at cosmic noon

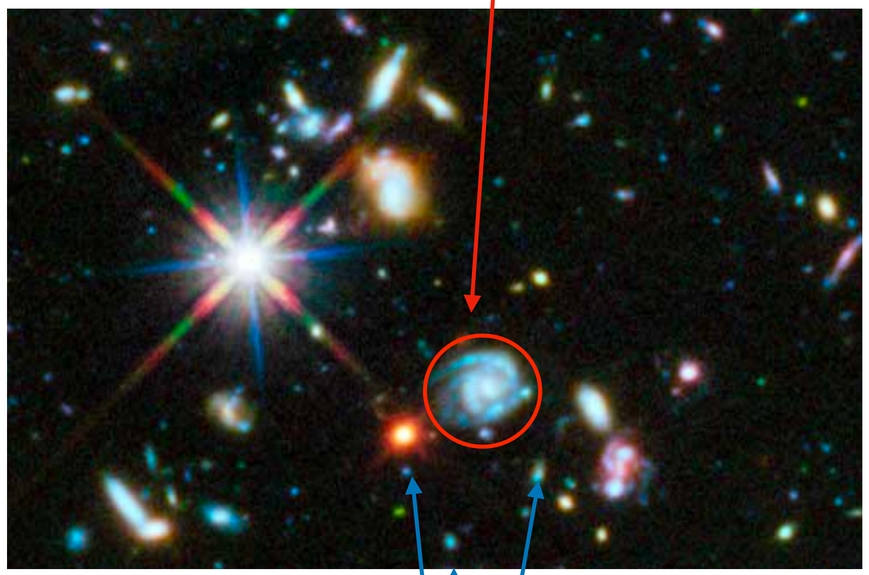
VUDS | VIMOS Ultra Deep Survey

The CGM is where the interplay between galaxy and IGM takes place

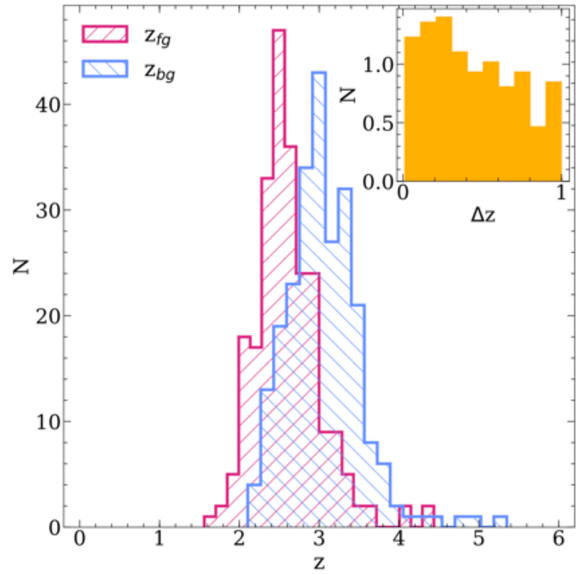


How to probe it?

Target foreground galaxy



CGM probed by background sources at different impact parameters



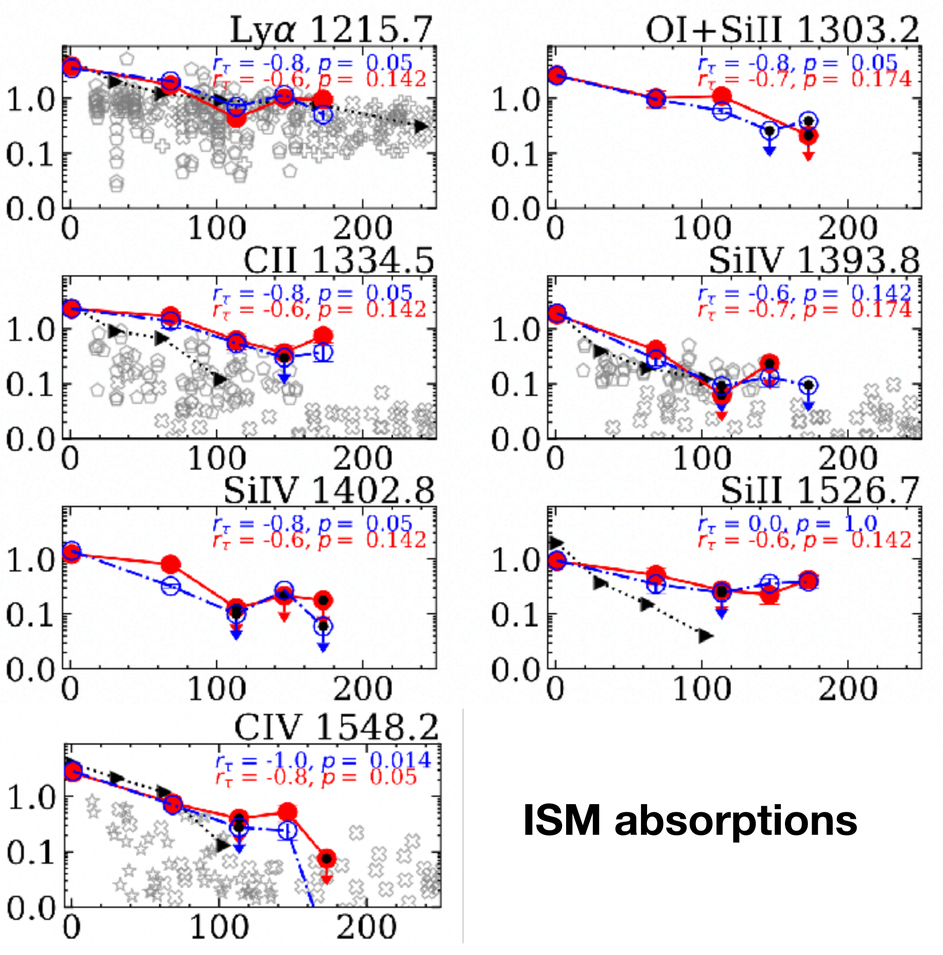
- 238 projected pairs (thanks to VUDS good spectral sampling)
- Only good quality redshifts
- $\langle z_{fore} \rangle = 2.5$

Stacks of tens of VUDS background spectra

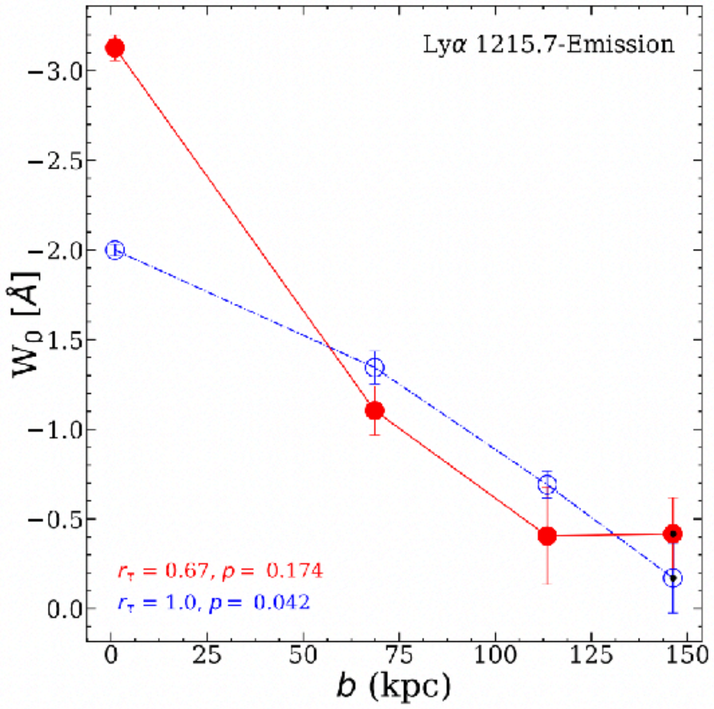
Méndez-Hernandez, PC, et al. (2022)

VUDS | VIMOS Ultra Deep Survey

CGM at cosmic noon

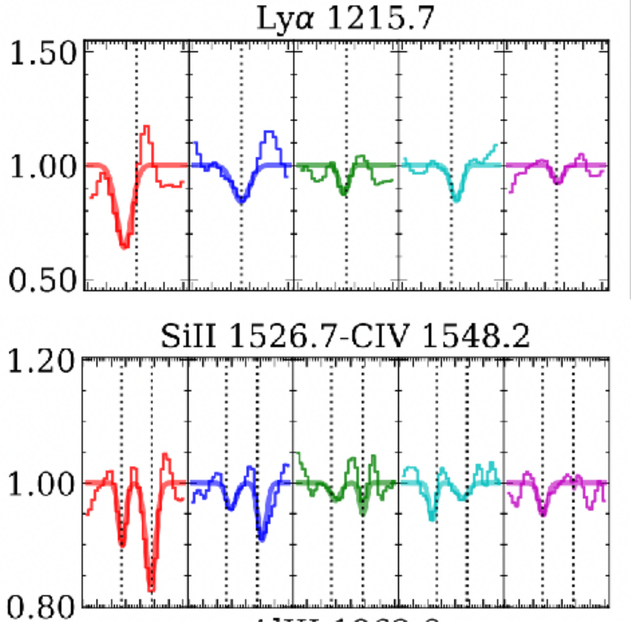


ISM absorptions



Lyα emission

- HIS (LIS) detected up to 146 (172) kpc
- Stronger absorption than at lower z
- Decreasing Lyα with impact parameter up to 150 kpc



Méndez-Hernandez, PC, et al. (2022)

Synergy with ALMA

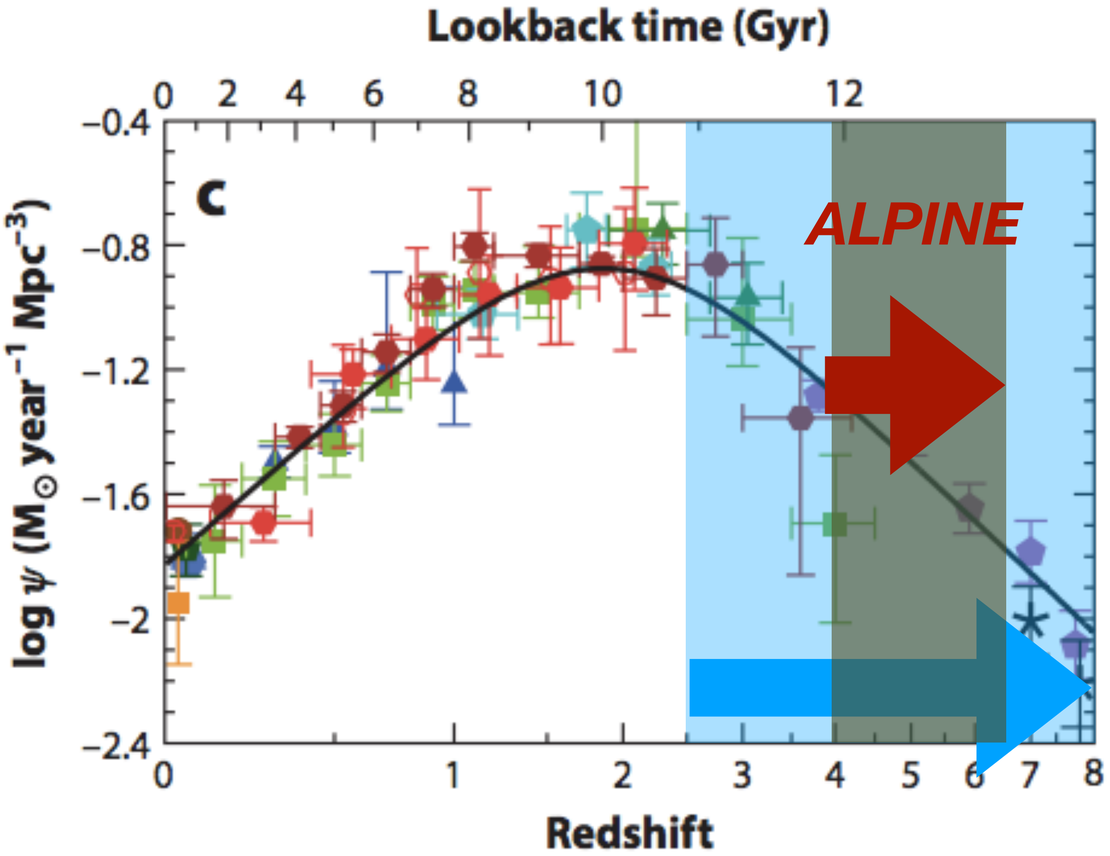
ALPINE: The ALMA Large Program to INvestigate CII at Early times

PI: Olivier Le Fèvre

Co-PIs: M. Béthermin, P. Capak, P. Cassata, A. Faisst, D. Schaerer, J. Silverman, L. Yan

Co-Is: Amorin, Bardelli, Boquien, Cimatti, Dessauges-Zavadsky, Dunlop, Giavalisco, Hathi, Hemmati, Hughes, Ibar, Jones, Koekemoer, Lagache, Lemaux, Maiolino, Masters, Nagao, Narayanan, Oesch, Pavesi, Pforr, Pozzi, Riechers, Rujopakarn, Talia, Tasca, Thomas, Toft, Tresse, Vallini, Vergani, Walter, Wei-Hao Wang, Zamorani, Zucca

Motivation



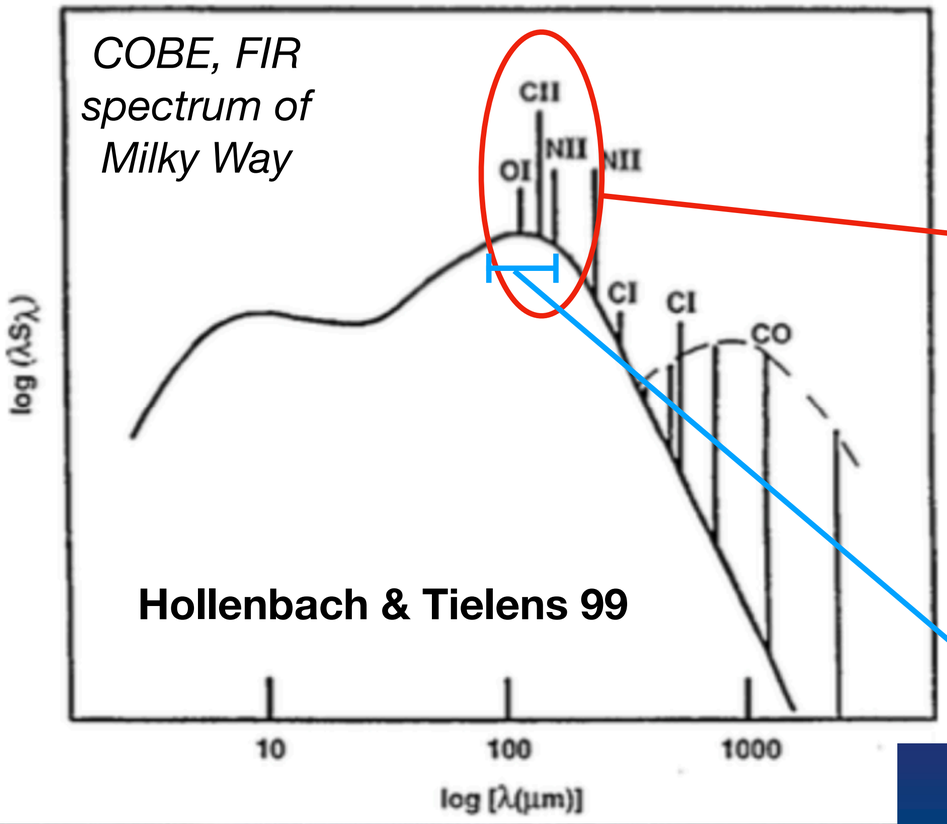
SFRD(z)

- increased by 10x in the first 3 Gyr after Big Bang
- peak z ~ 2
- decreased by 10x since

Based on UV only

We have a biased view of the Universe at z > 3

What is ALPINE ?



ALMA LP: 70h cycle 5

[CII] line:

- one of the main coolants for the ISM
- brightest FIR line: L[CII]/ L[FIR]~0.1-0.3%
- can be brighter than Lyα
- in the sub-mm/mm range at 4.5<z<9

Traces SF?

158 μm rest-frame:

- traces the peak of the dust thermal emission

Dust obscured star-formation

Main science goals

See Andreas' talk

- [CII] as a ***SFR indicator***
- A first comprehensive and precise (< 20%) measurement of the ***SFRD at 4 < z < 6*** from UV+FIR continuum and C+ emission
- A first detailed characterization of ***ISM properties*** using LFIR/LUV and C+/FIR diagnostics
- A first measurement of ***dynamical masses*** from spectrally resolved C+, combined with stellar masses and estimates of DM halo masses to measure ***the gas fraction*** and its evolution

1. Obscured SF in UV selected samples

ALPINE is a UV rest-frame selected sample

- Bright enough to get spectro-z
- SFR selection, not a volume limited sample

What is the amount of the dust obscured SF in these galaxies?

$$SFRD = SFRD_{FUV,uncorr} + SFRD_{IR}$$

From UV-Optical

From ALMA continuum

Only 23/118 continuum detections → ***stacking***

1 Stack FIR continuum images in bins of $M_\star$ or M_{FUV}

2 Measure the flux on stacked images and convert it to IR luminosity $\langle L_{IR} \rangle$

3 Derive correlation F_{FIR} - $M_\star$ or F_{FIR} - M_{FUV}

4 Define proxy density - ϕ in bins of $M_\star$ or M_{FUV}

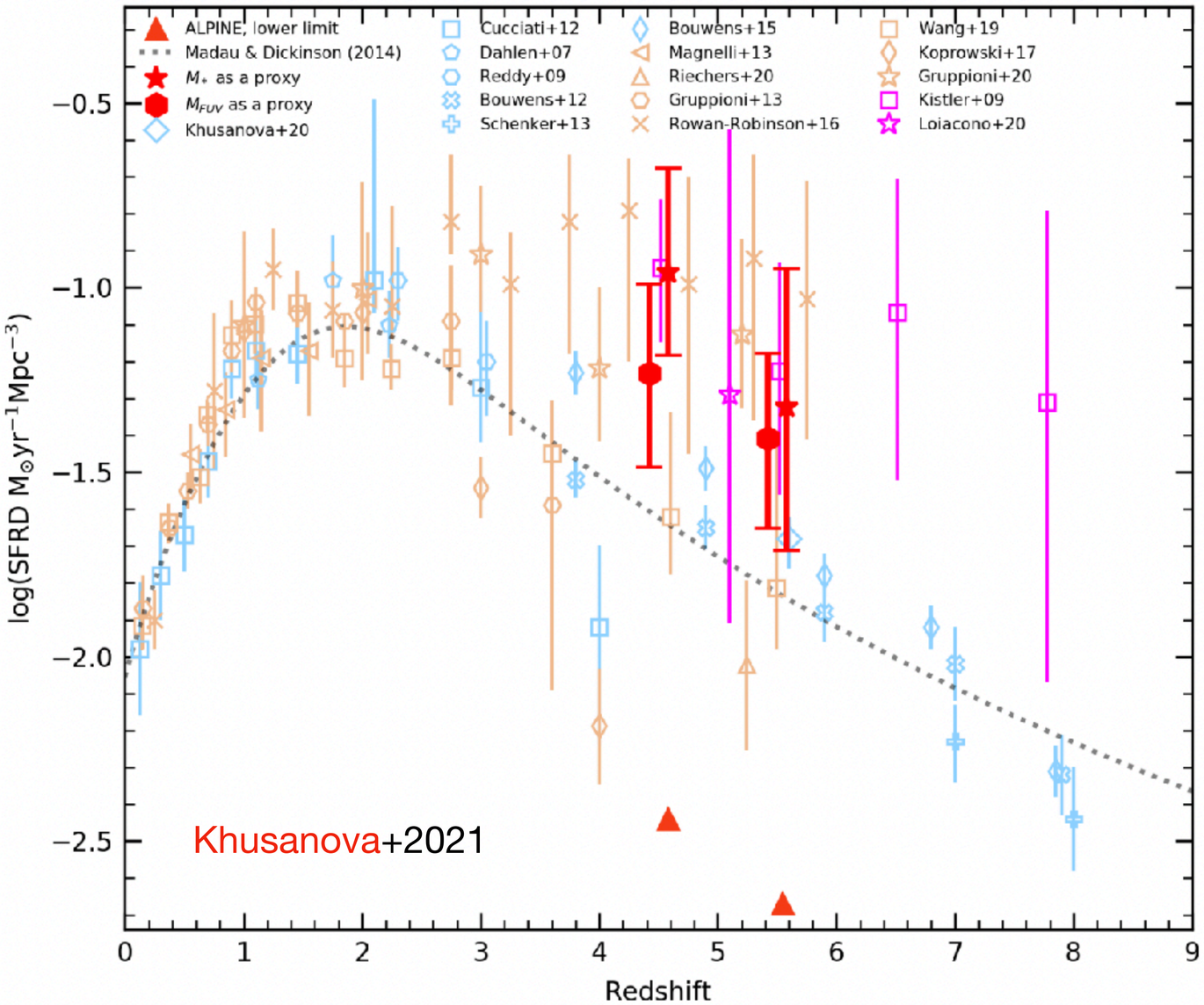
$$\rho_{IR} = \int \langle L_{IR} \rangle(x) \phi(x) dx$$

5 Derive IR luminosity density ρ_{IR} using Eq. 3, where x is $M_\star$ or M_{FUV}

6 Convert ρ_{IR} to $SFRD_{IR}$.

Khusanova+2021

1. Obscured SF in UV selected samples



Dust emission based estimates

Dust-corrected UV estimates

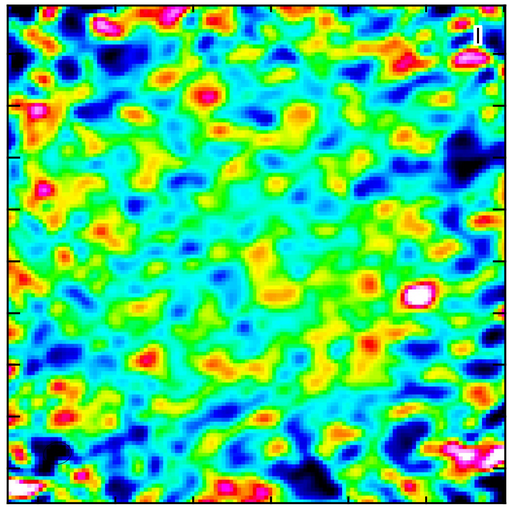
ALPINE

Constant SFRD at z > 3??

UV based estimates seem to understimate the total SFRD by 60%

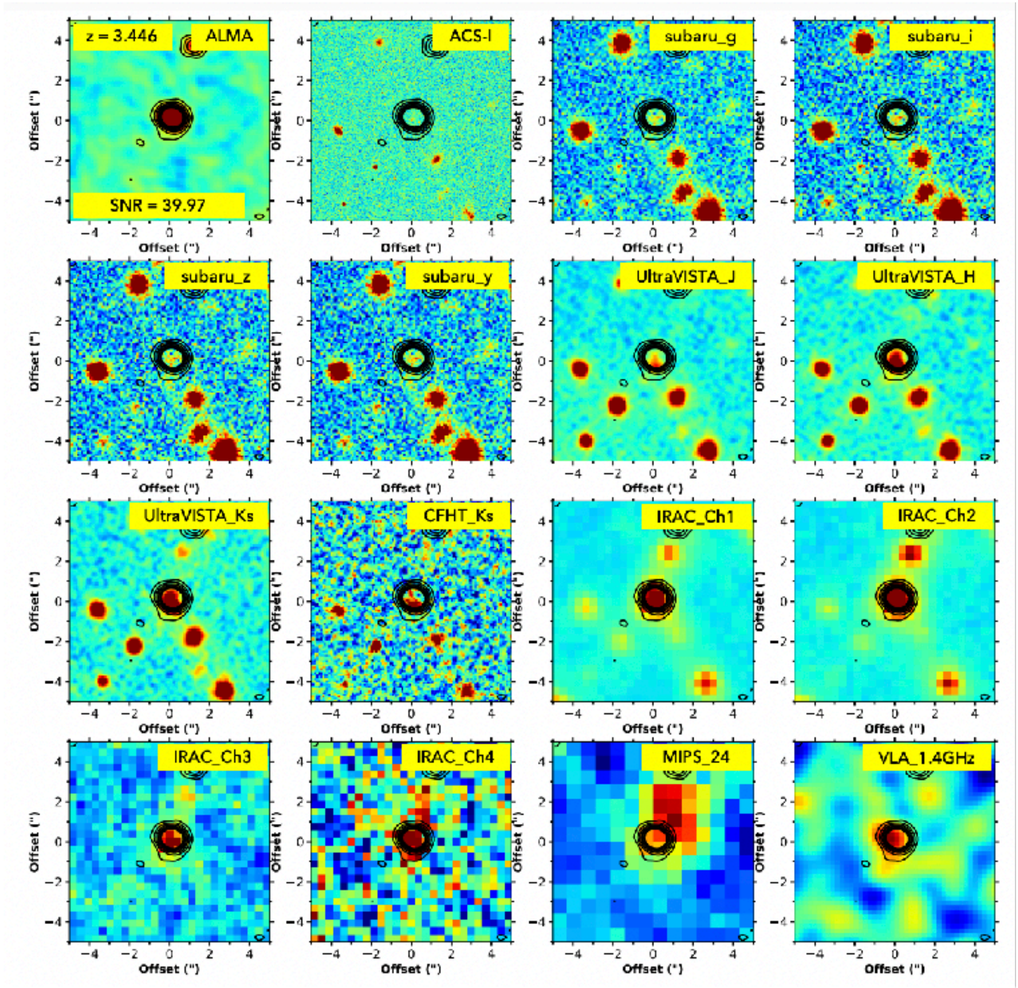
2. SF in UV-optical dark galaxies

But what about the contribution of dust-obscured galaxies to the SFRD?

118x 

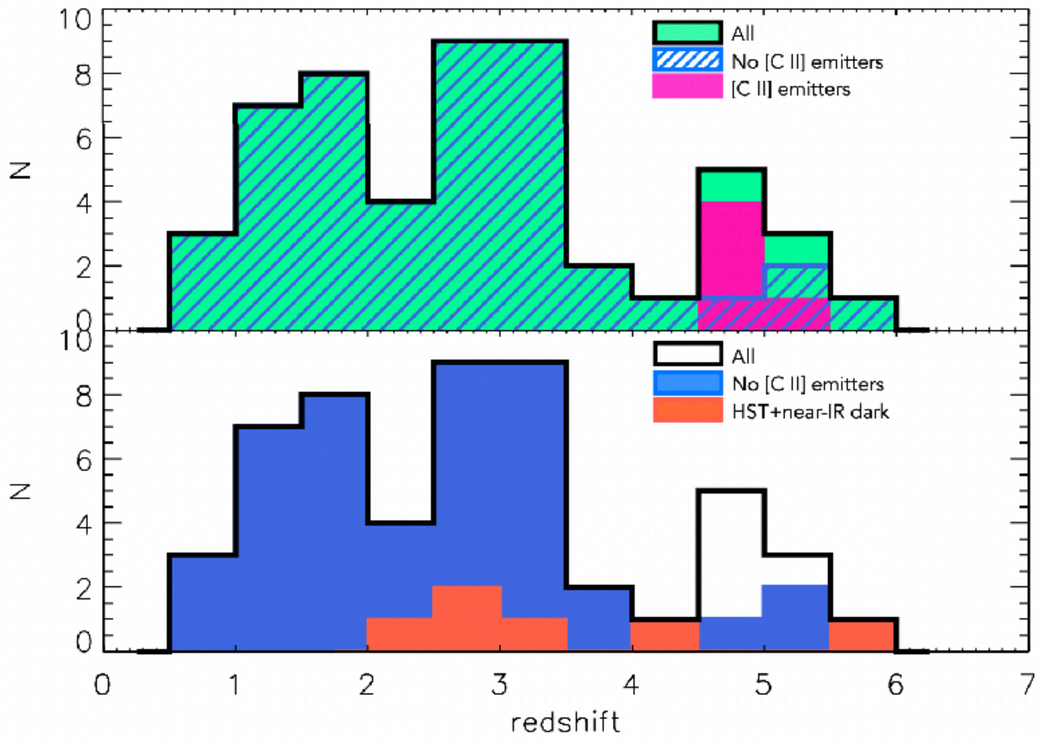
= 25 arcmin^2 survey area

Gruppioni+2020



56 UV-optical dark sources

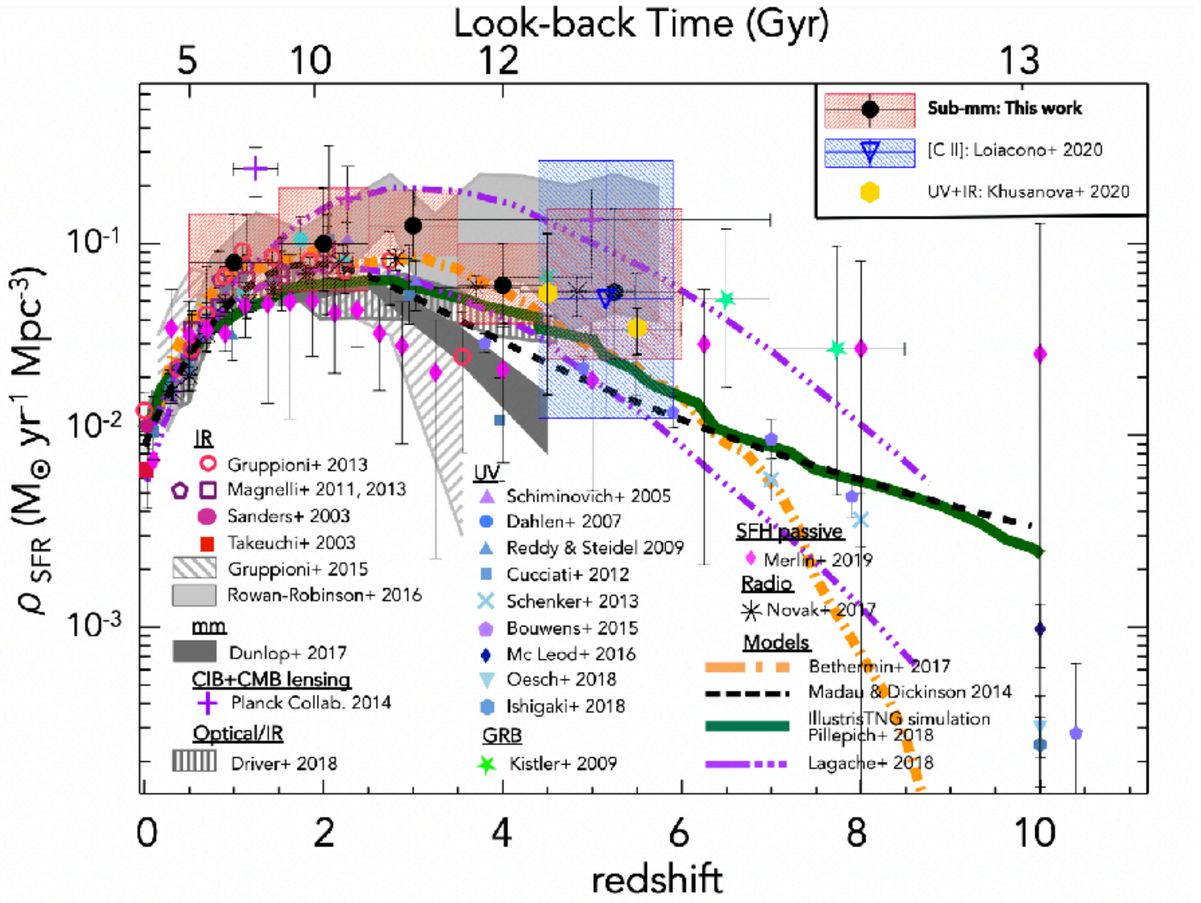
2. SF in UV-optical dark galaxies



Redshift distribution

Gruppioni+2020

SFRD

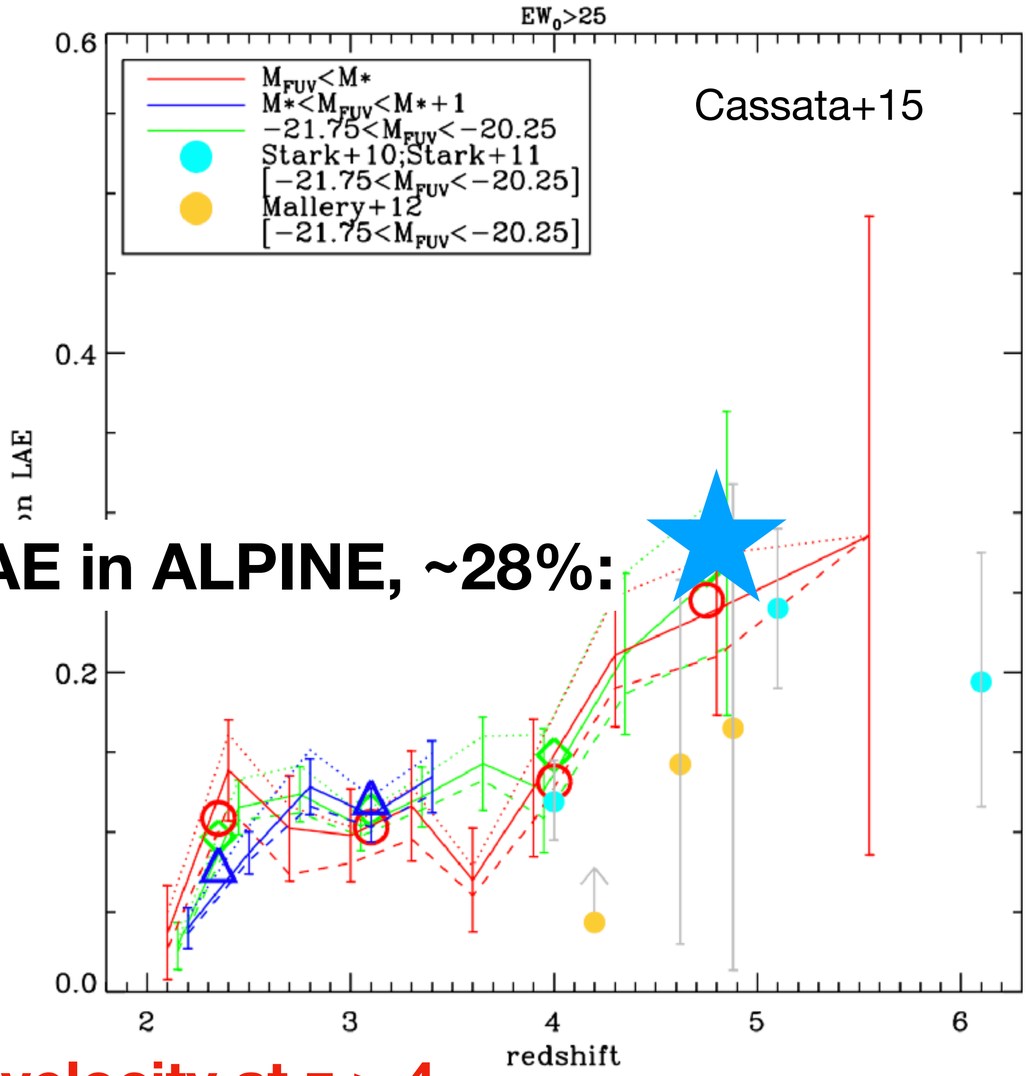


Systematically above Madau&Dickinson14

A2C2S | ALMA ALPINE [CII] Survey

Unplanned 2: ISM at cosmic dawn with Lya and [CII]

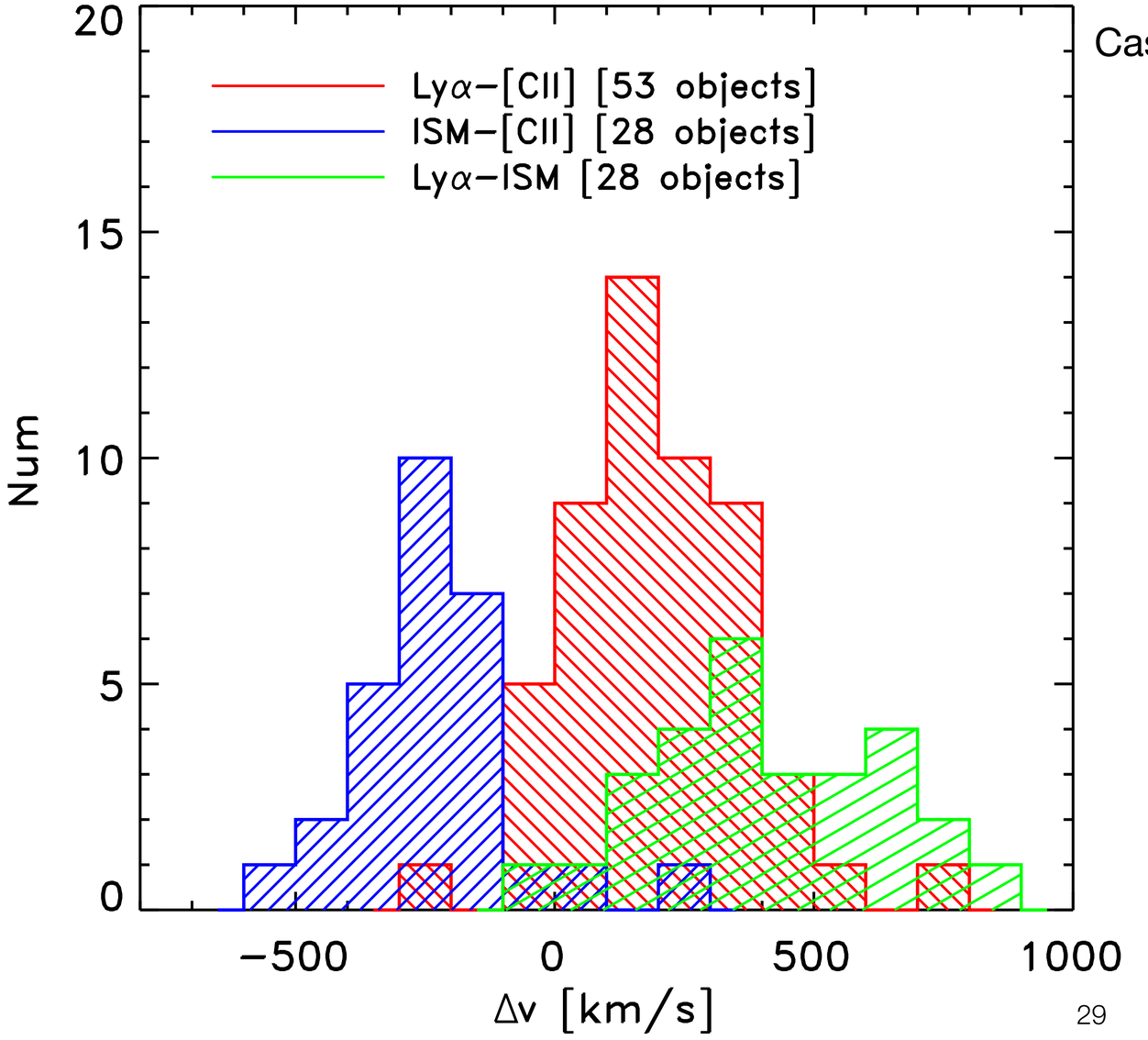
- 53 galaxies at 4.5 < z < 6
- **all main-sequence**
- **fraction of strong LAE: similar to other samples at same z**
- EW(Lya) > 4 A
- S/N([CII]) > 3.5
- 28 with ISM lines



Fraction of strong LAE in ALPINE, ~28%:

The largest sample with Lya and systemic velocity at z > 4

Δv Lya, Δv ISM

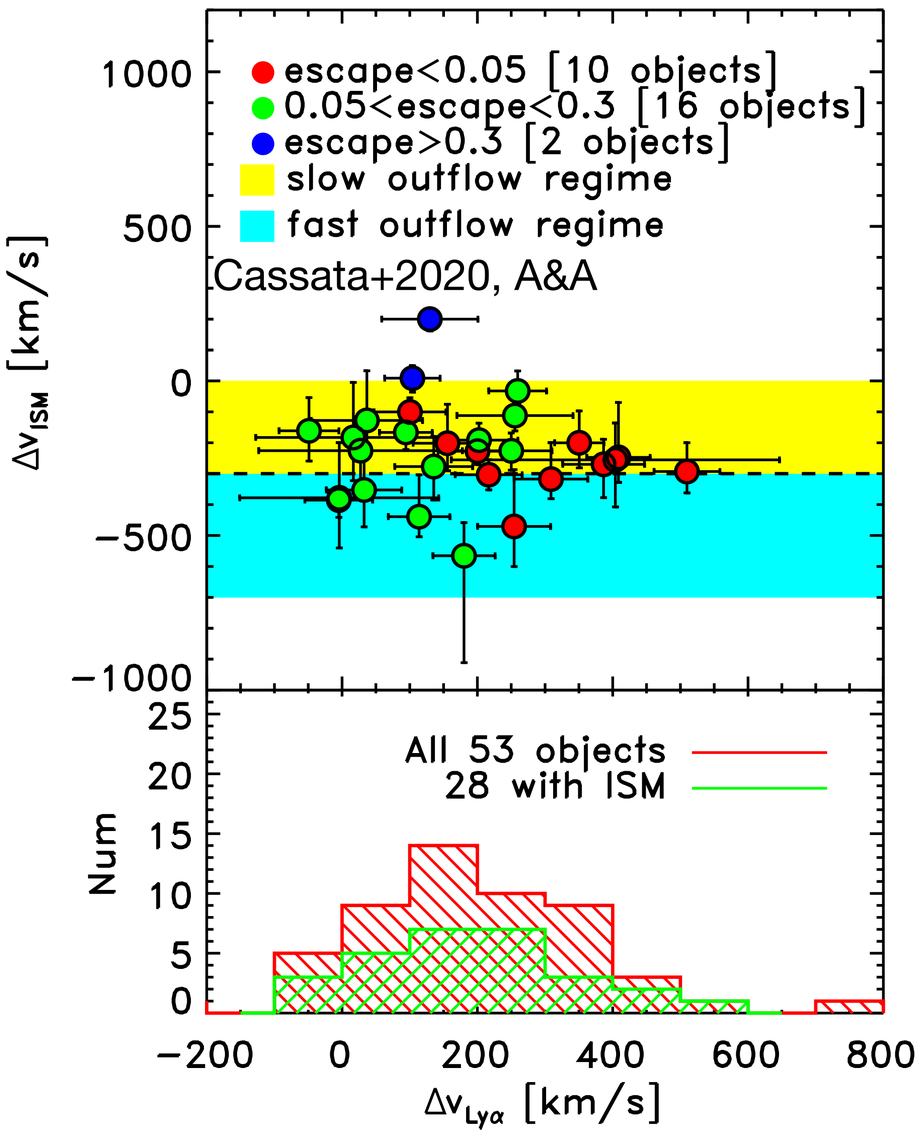


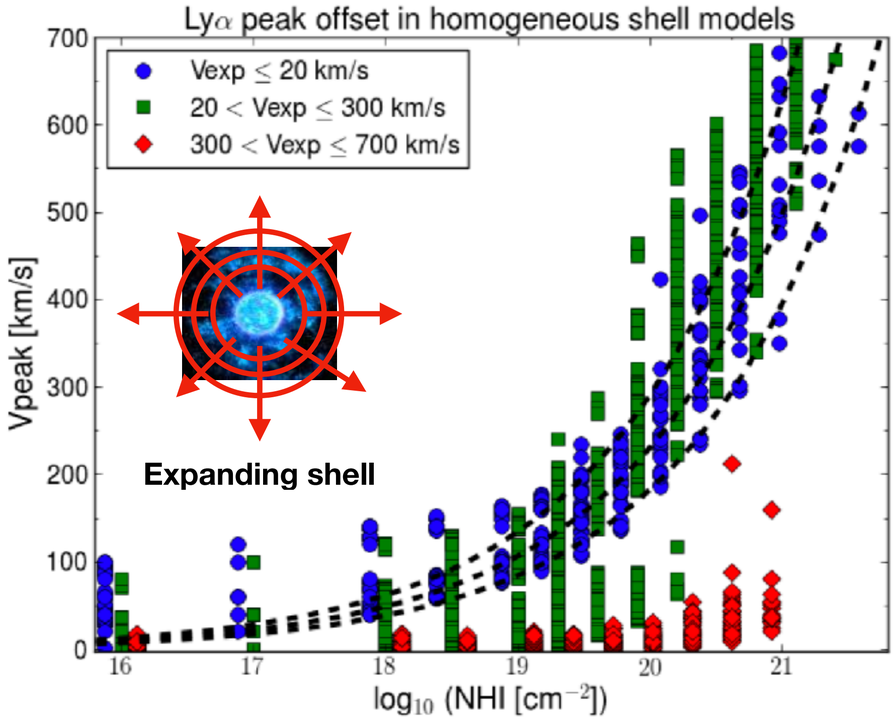
Cassata+2020, A&A

- **Lya-[CII] < 500 km/s (peak at 200 km/s)**
- **-500 < ISM-[CII] < 0 km/s (peak at -200 km/s**
- **0 < Lya-ISM < 800 km/s (peak at 400 km/s)**

Evidence for outflows

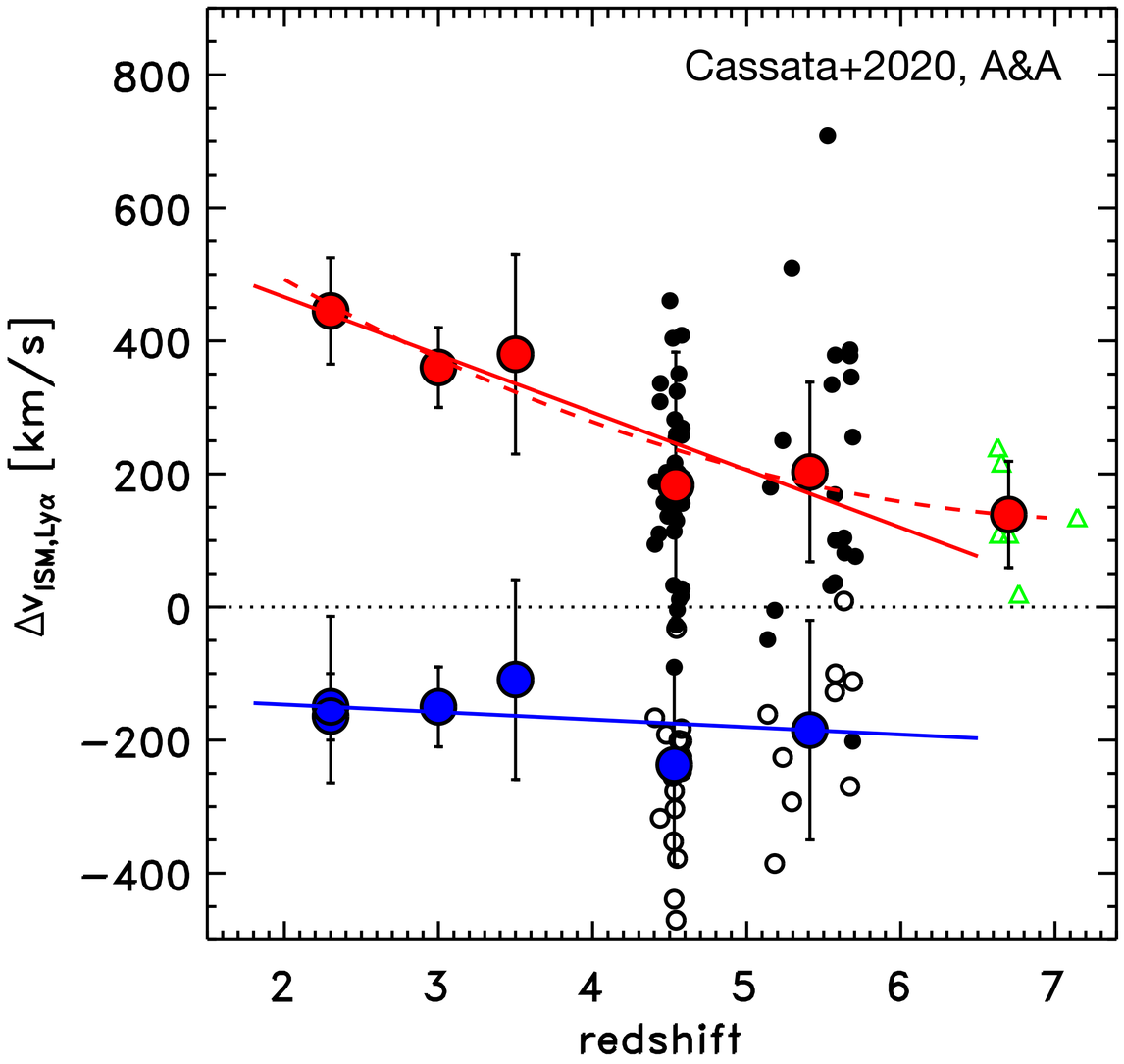
Uniform shell model





- Outflows favour Lya escape:
  - fast outflow regime: larger Lya escape fractions, small Lya offsets
  - slow outflow regime: the escape depends on NHI (or covering fraction)

Comparison with low z

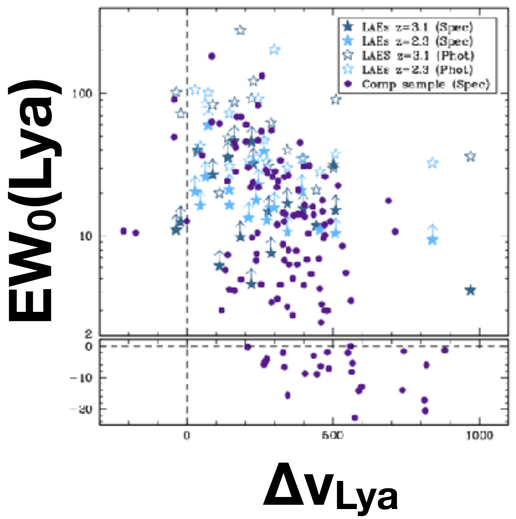


Upper panel: Δv_{Lya} significant evolution

Lower panel: Δv_{ISM} no evolution

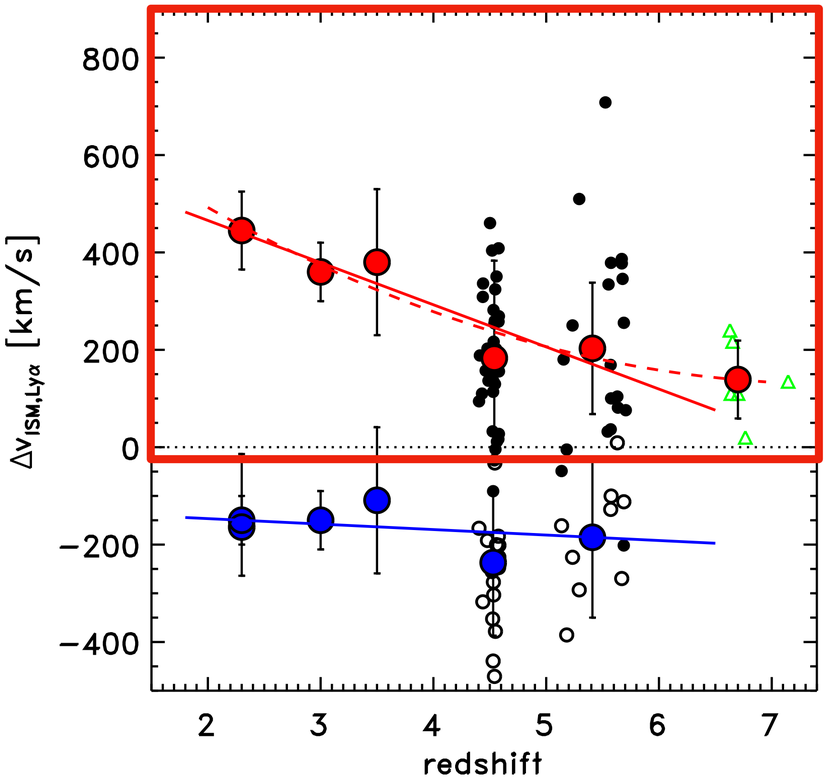
Evolution of f_{esc}, LAE

Δv_{Lya} correlates with EW(Lya) or f_{esc}(Lya)



+

Δv_{Lya} decreases with z



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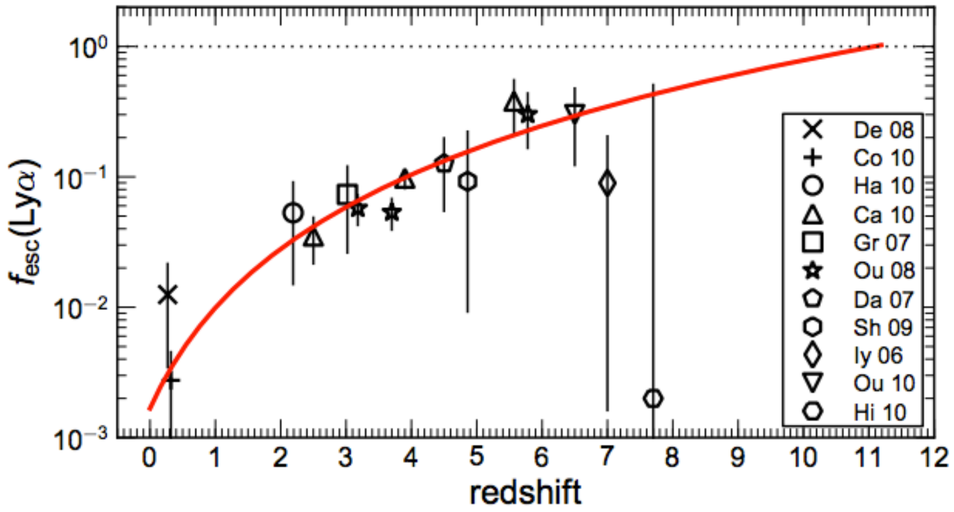

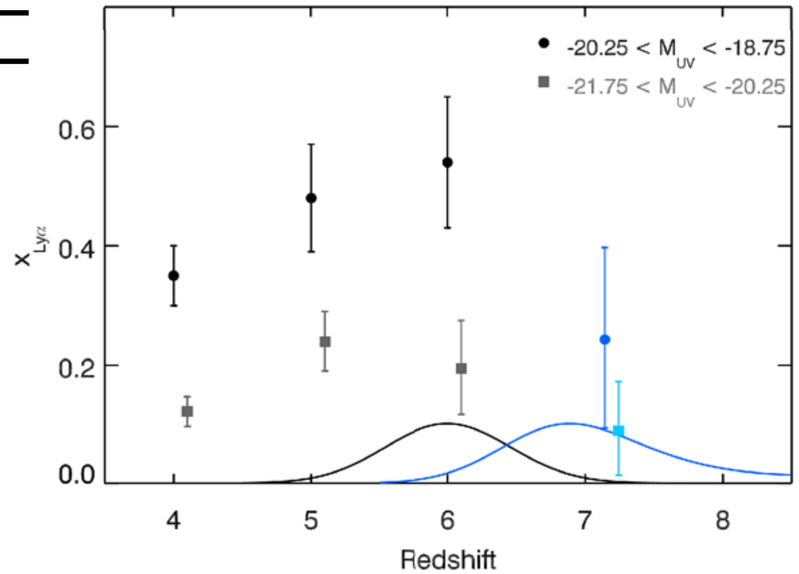

At the same time, no evolution of Δv_{ISM}

Conclusions?

This is just the beginning:

WEBB SPACE TELESCOPE

euclid

SuMIRe Prime Focus Spectrograph

MOSAIC

Olivier showed us the path, let's just follow it